Effects of Foveation on Early Visual Processing

Billy Broderick

April 14, 2022

Perceptual ability is not uniform across the visual field

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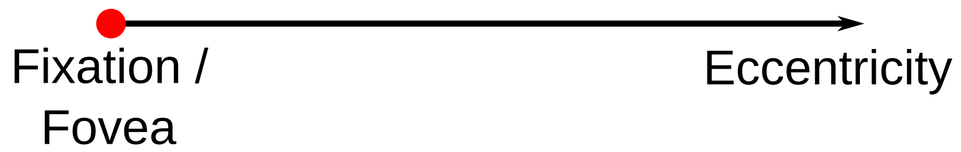

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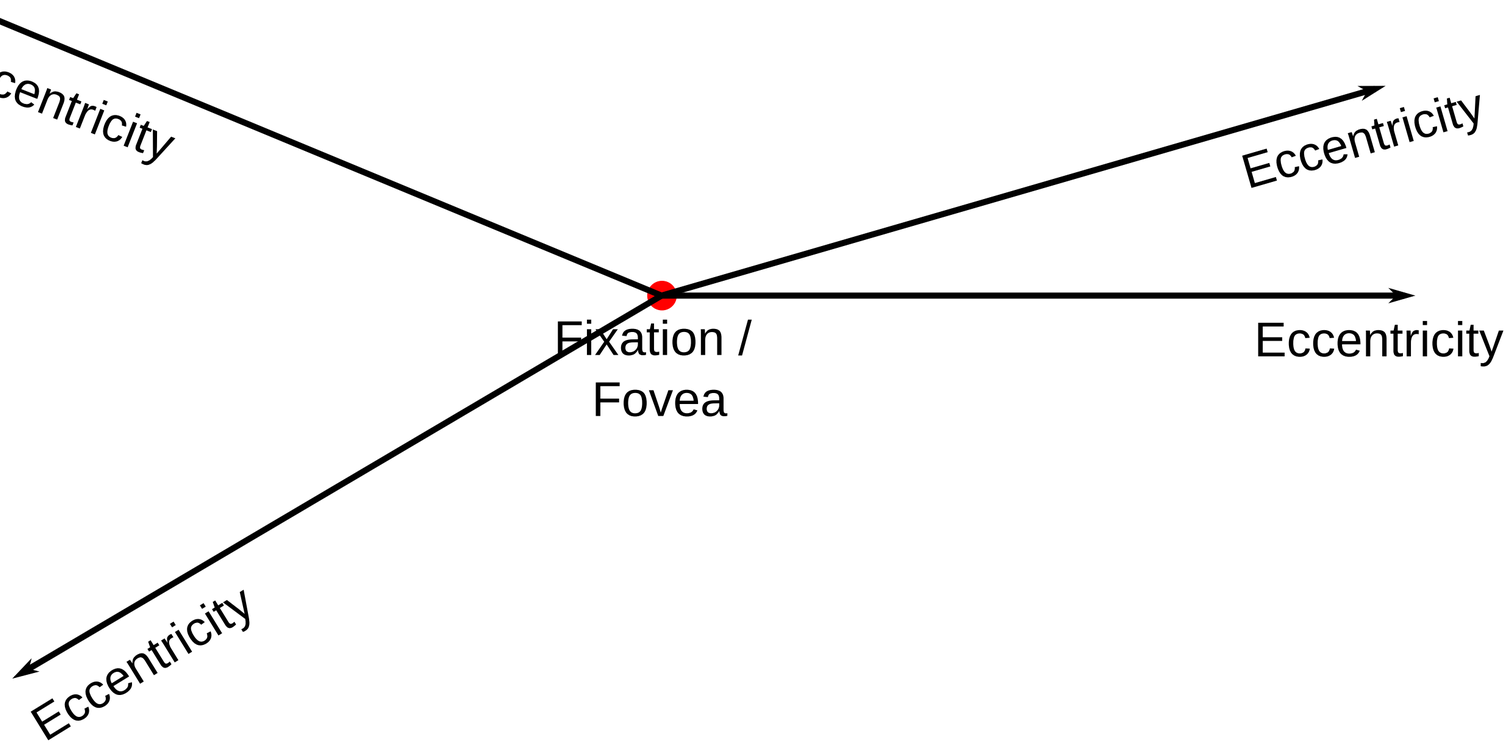

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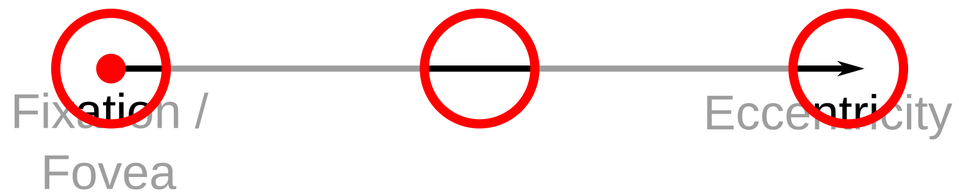
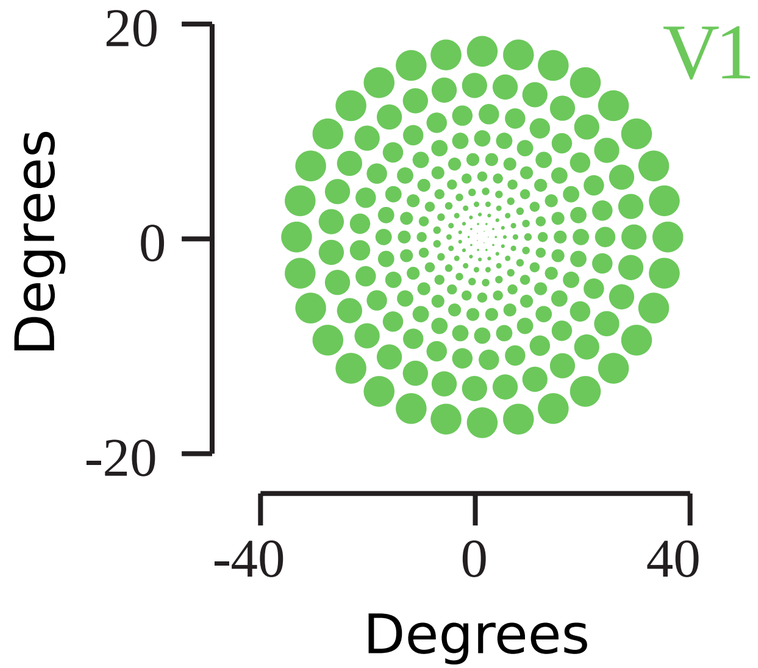
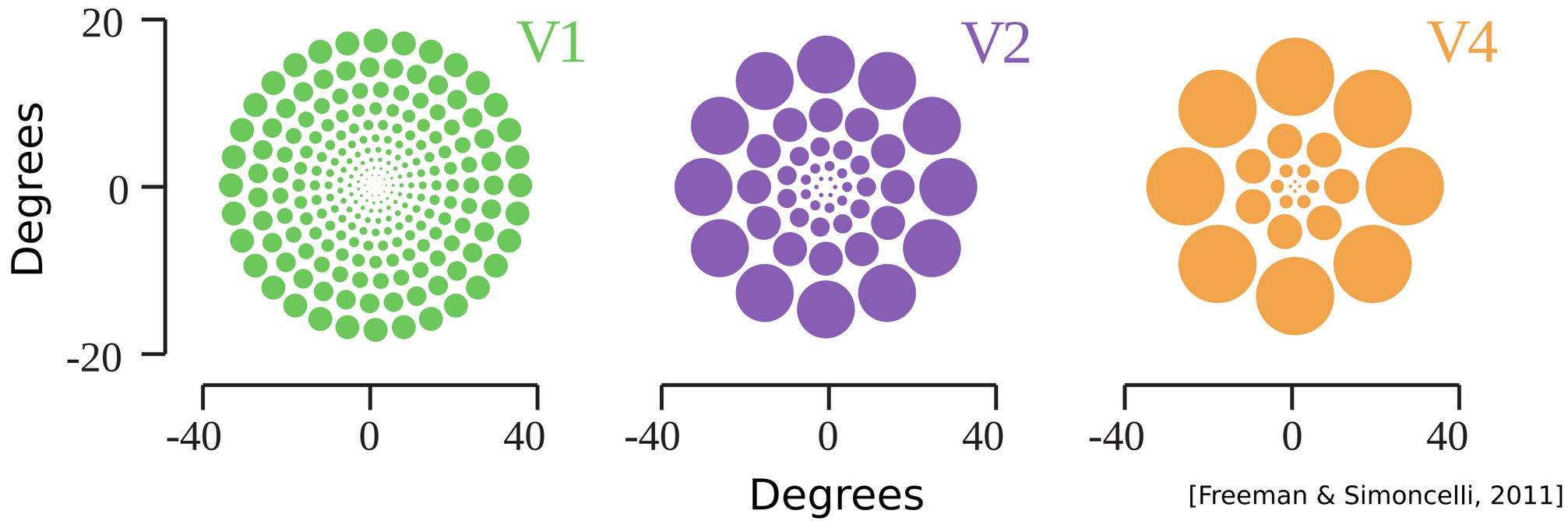


Receptive fields grow with eccentricity



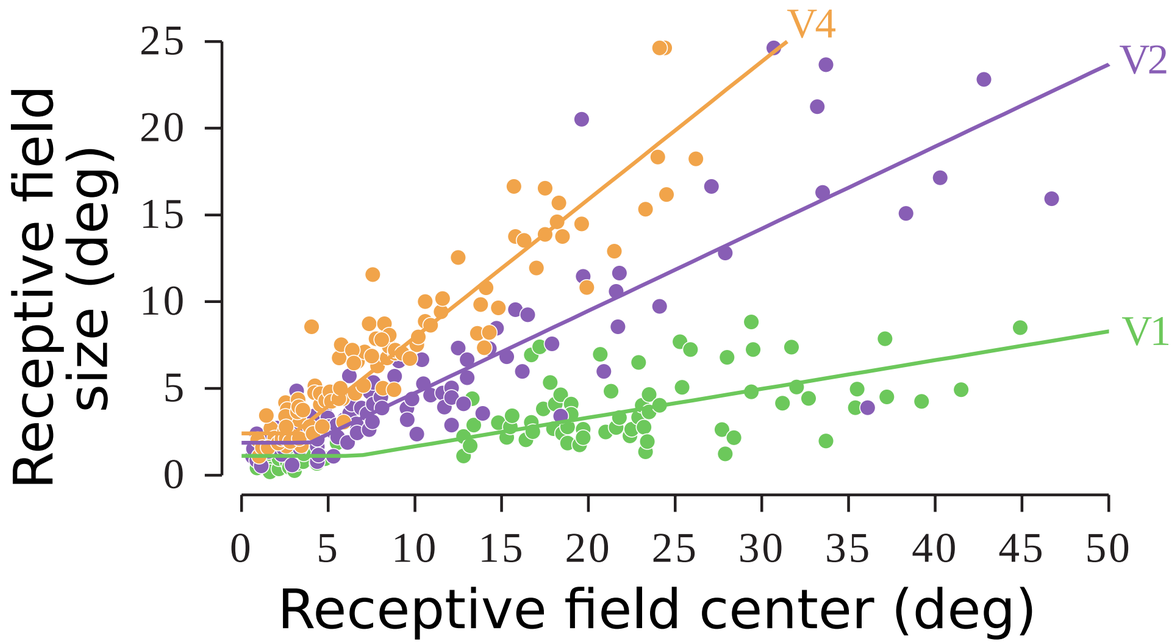
[Freeman & Simoncelli, 2011]

... and as you go up the visual hierarchy



[Freeman & Simoncelli, 2011]

Receptive fields grow linearly with eccentricity



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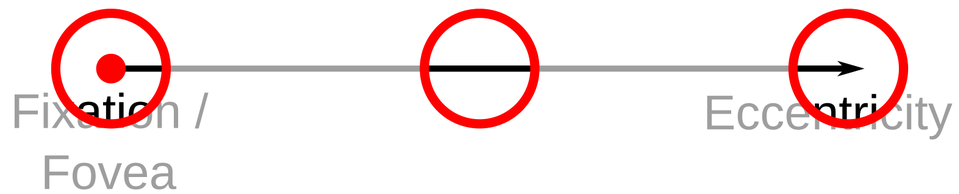

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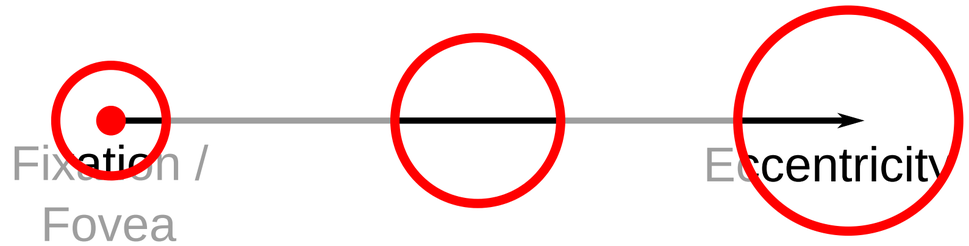
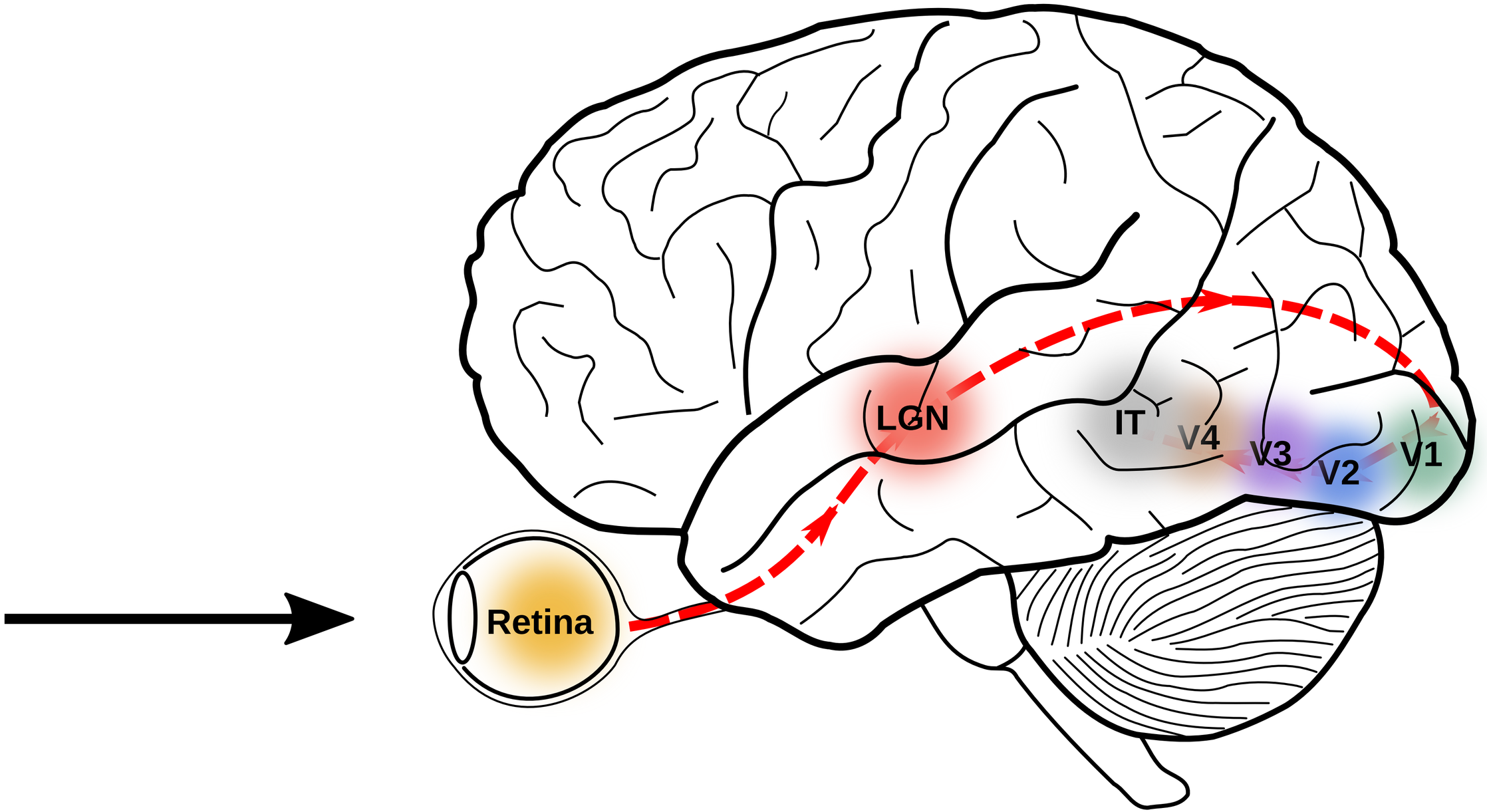


Foveation: the increase in size of visual neuronal receptive fields with eccentricity

What is the early visual system?

Visual system



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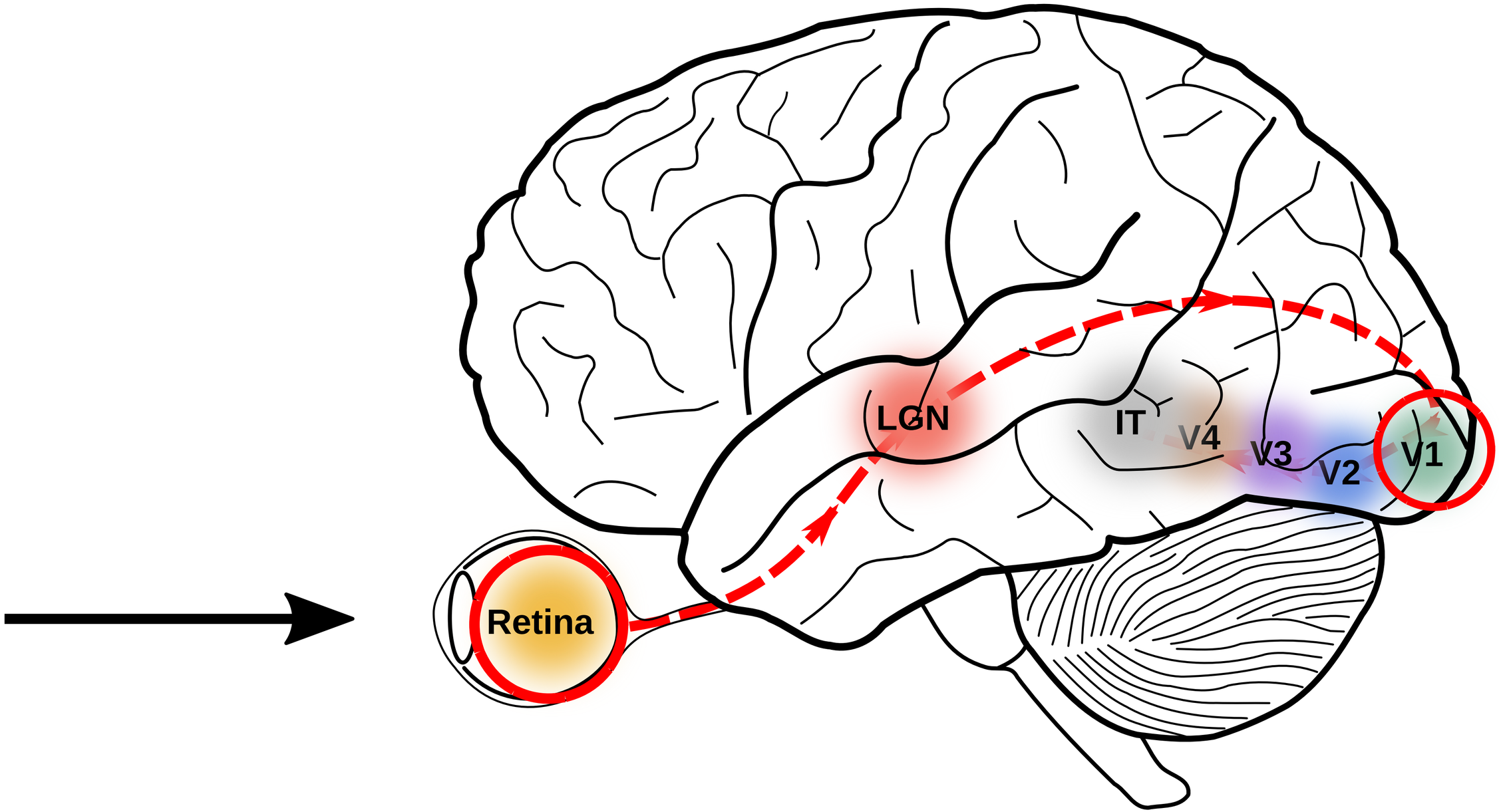

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By J. A. MOVSHON,* I. D. THOMPSON and D. J. TOLHURST
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DISCHARGE PATTERNS AND FUNCTIONAL ORGANIZATION OF MAMMALIAN RETINA*

STEPHEN W. KUFFLER
The Wilmer Institute, Johns Hopkins Hospital and University Baltimore, Maryland

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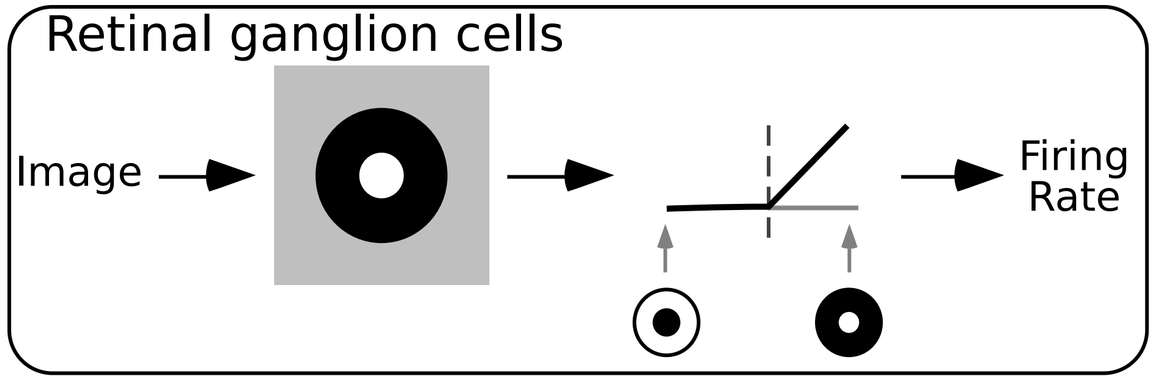

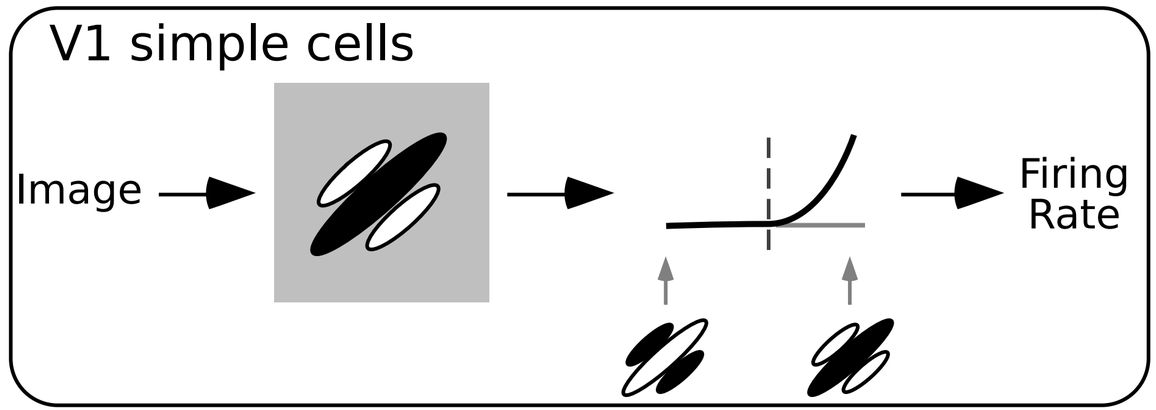

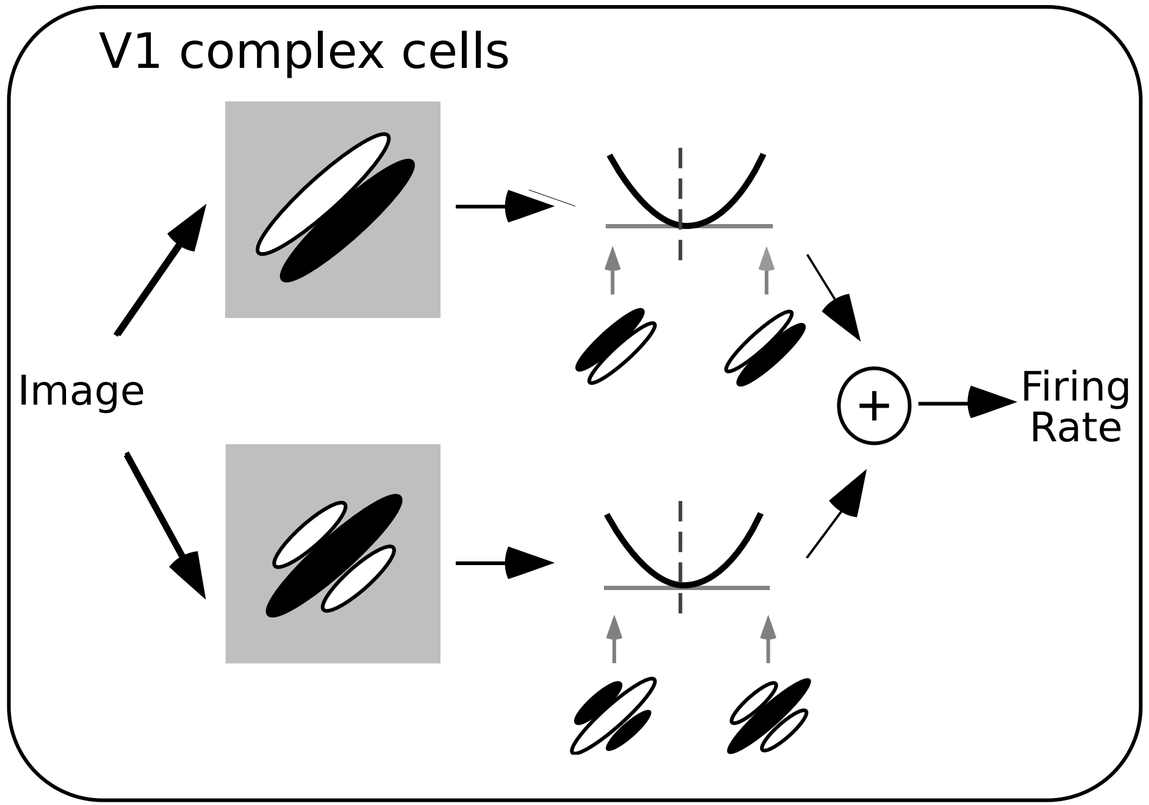

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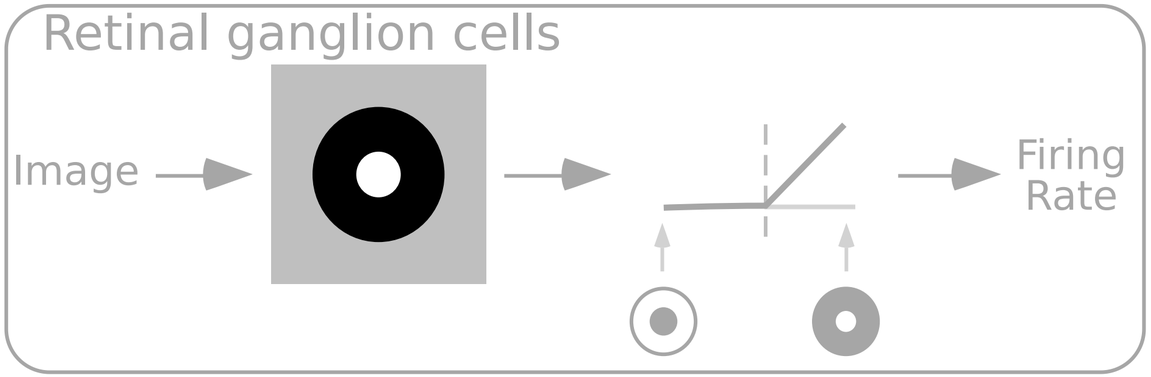

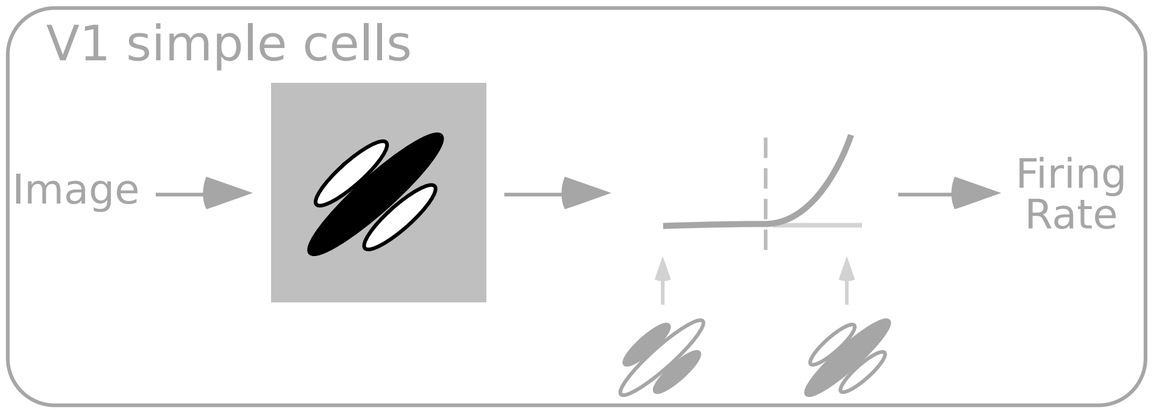

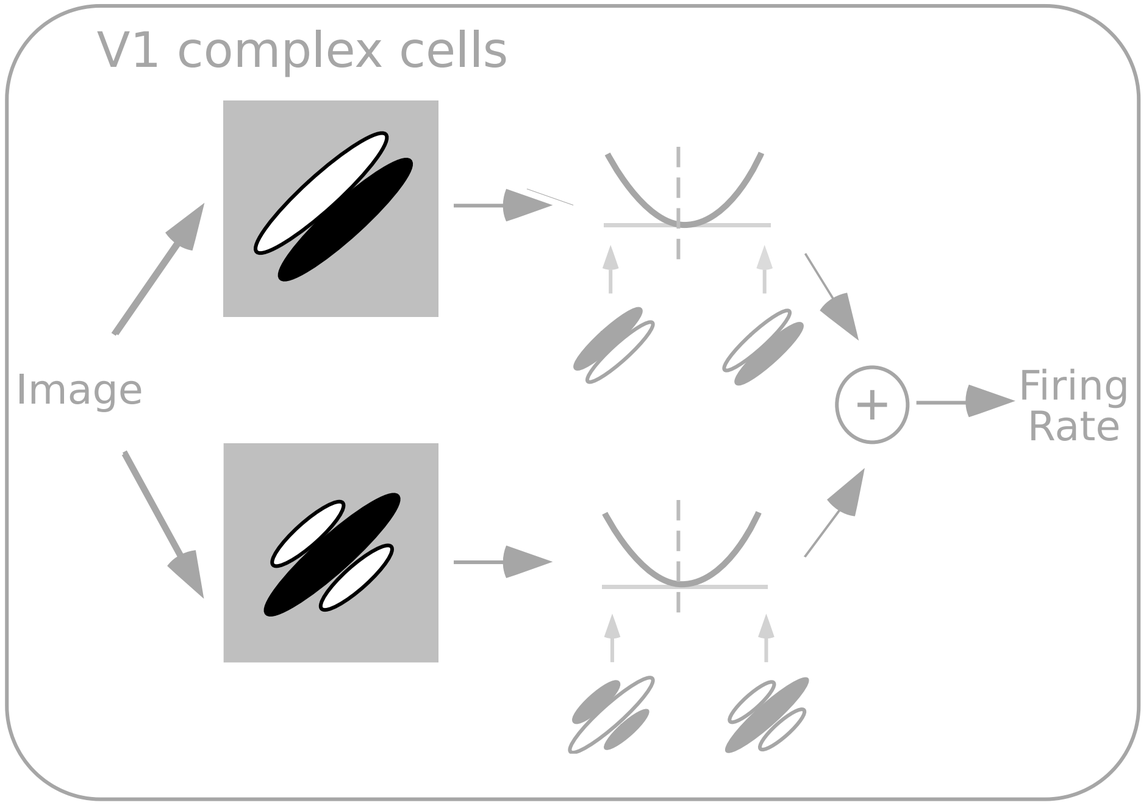

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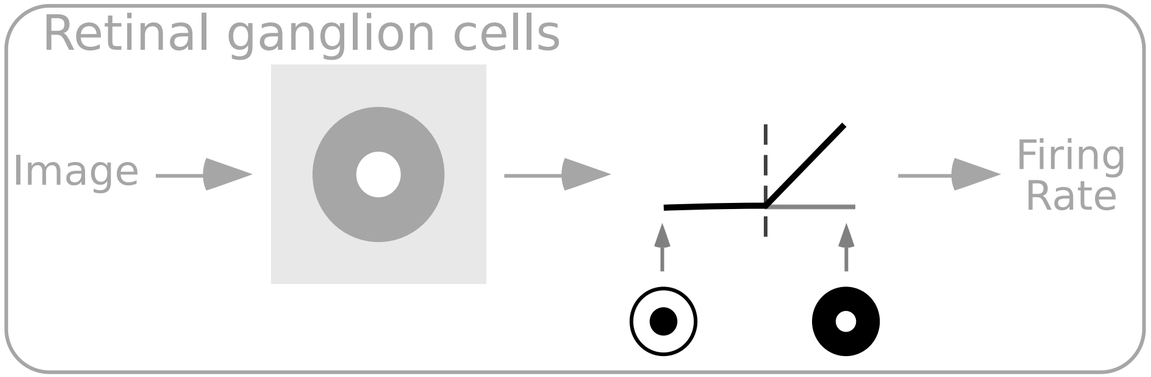

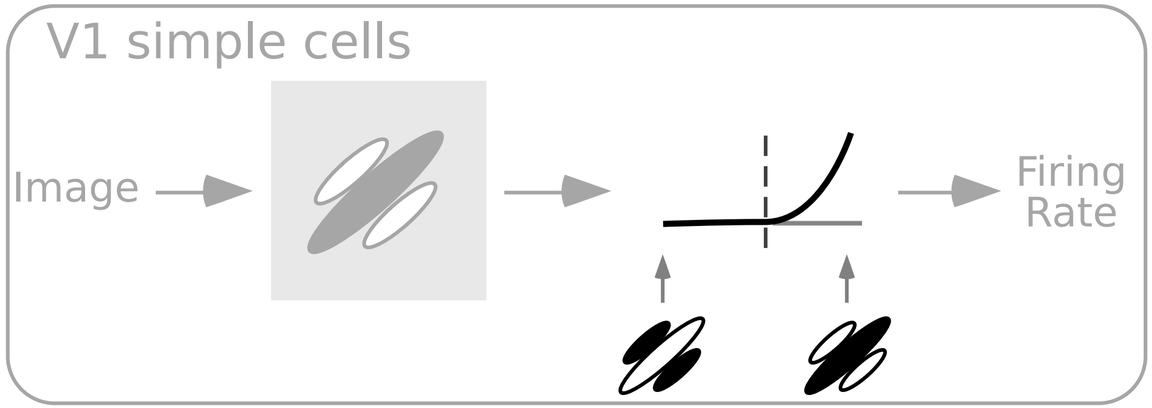

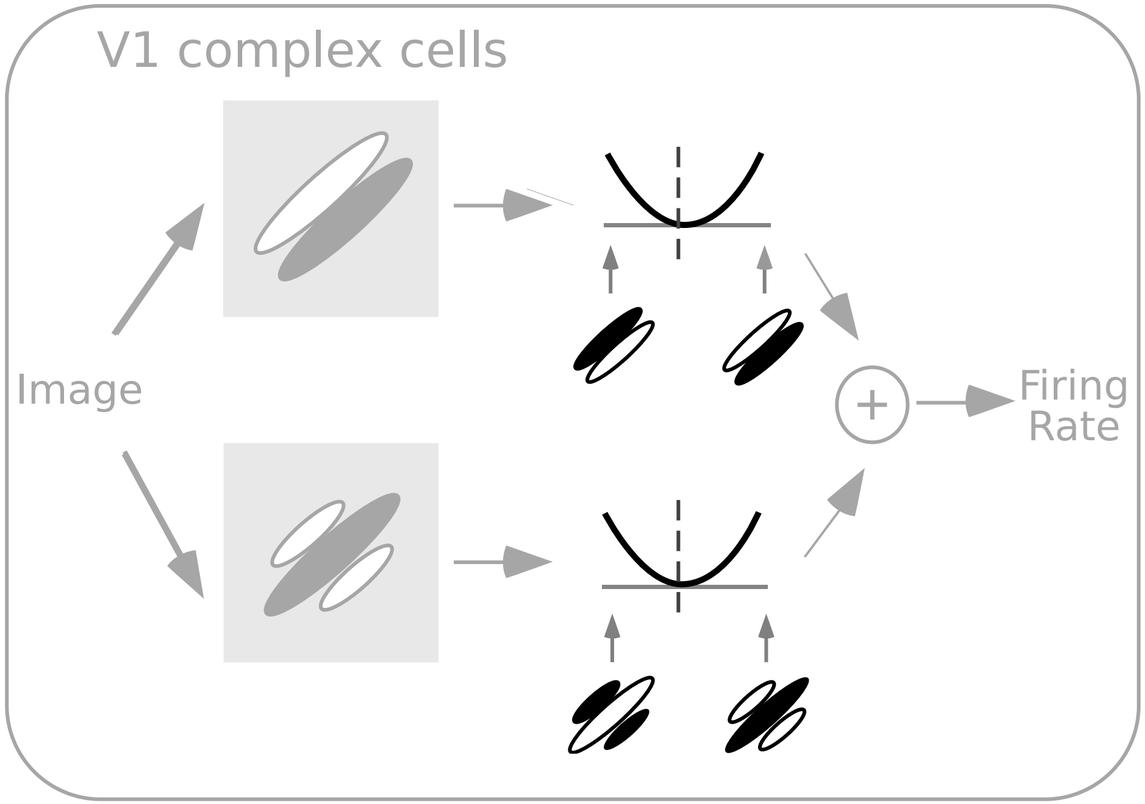

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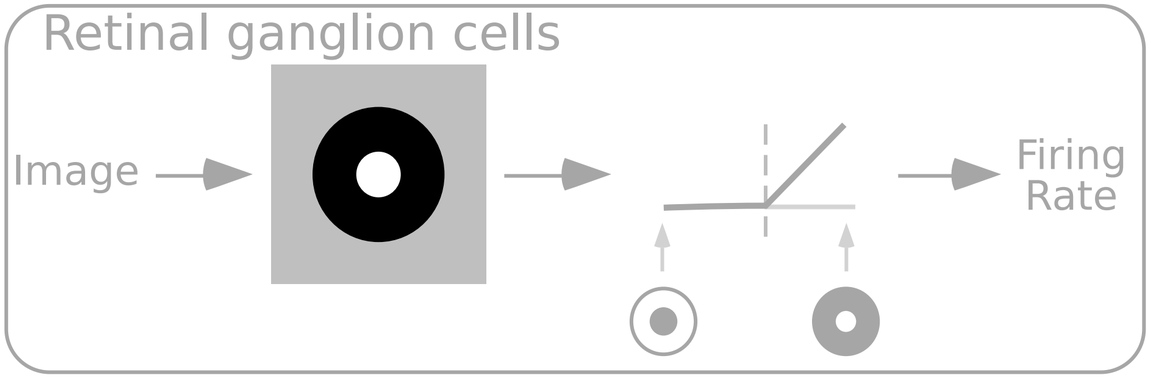
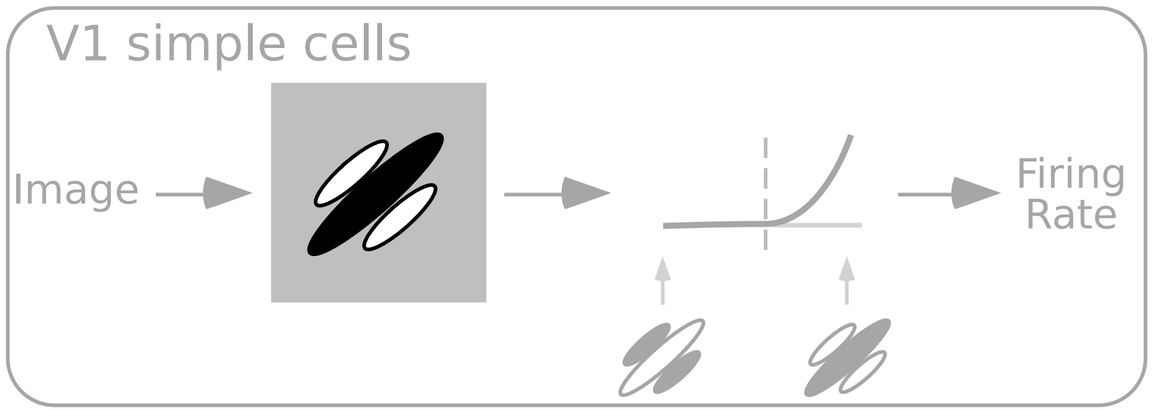
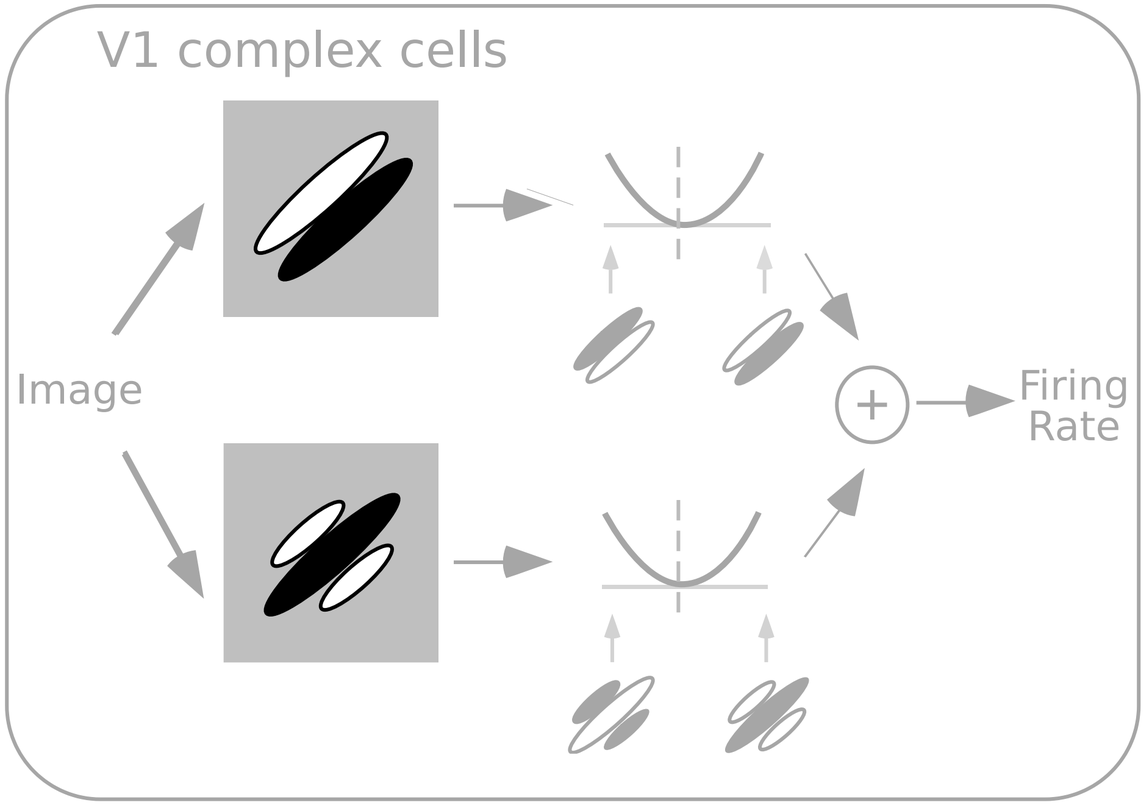
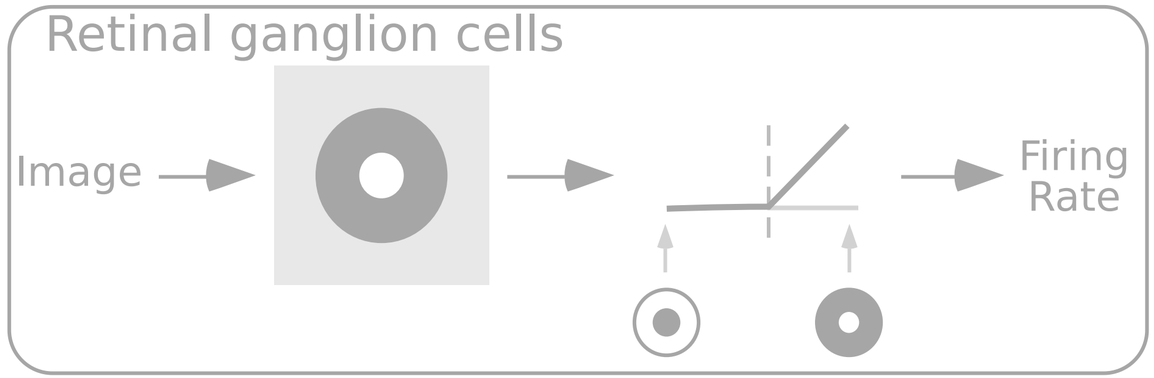
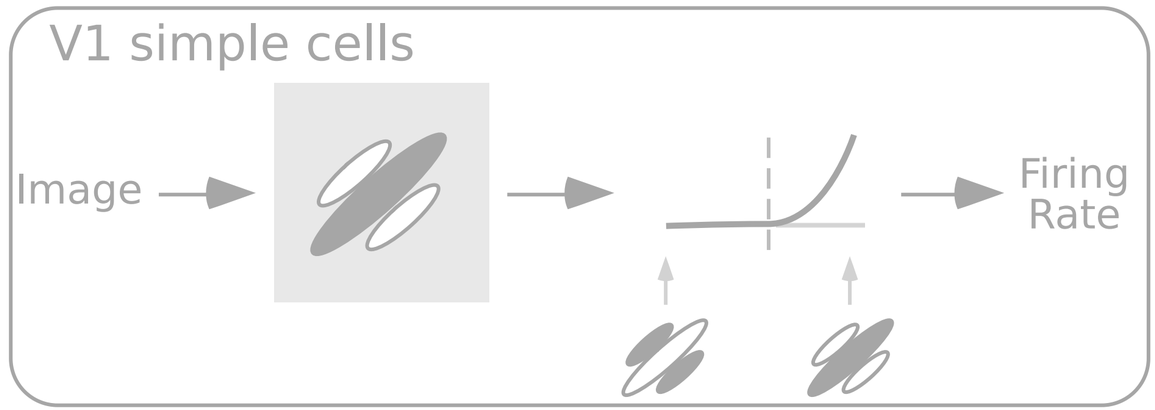


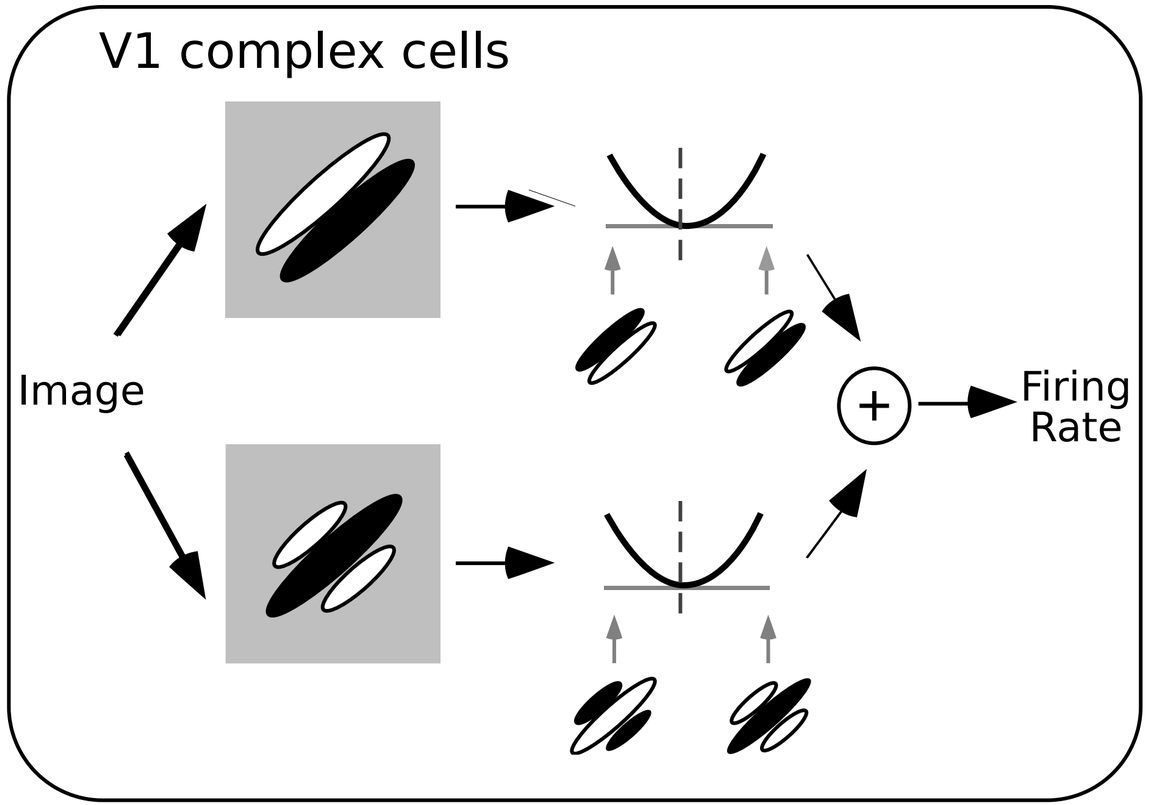




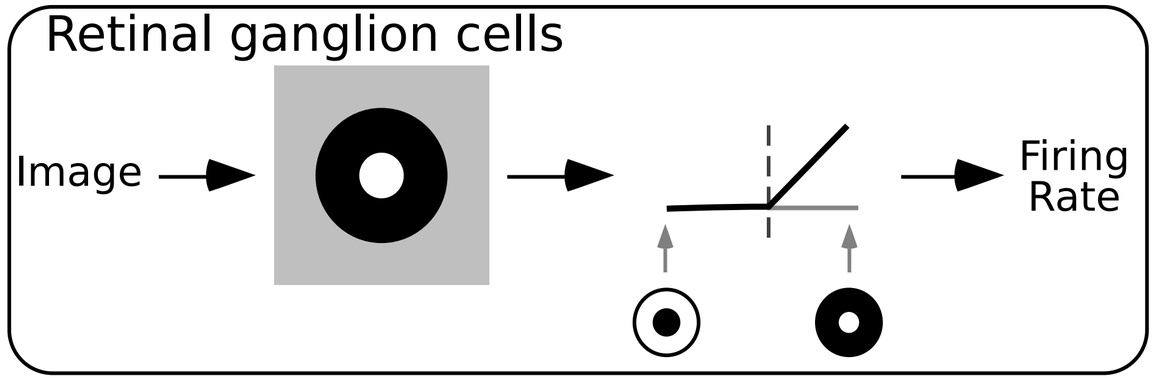
[Carandini et al, 2005]

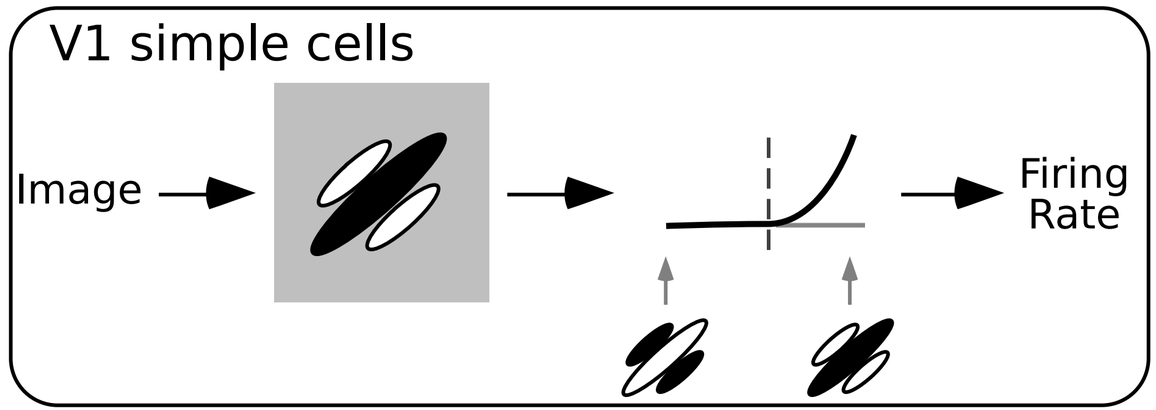


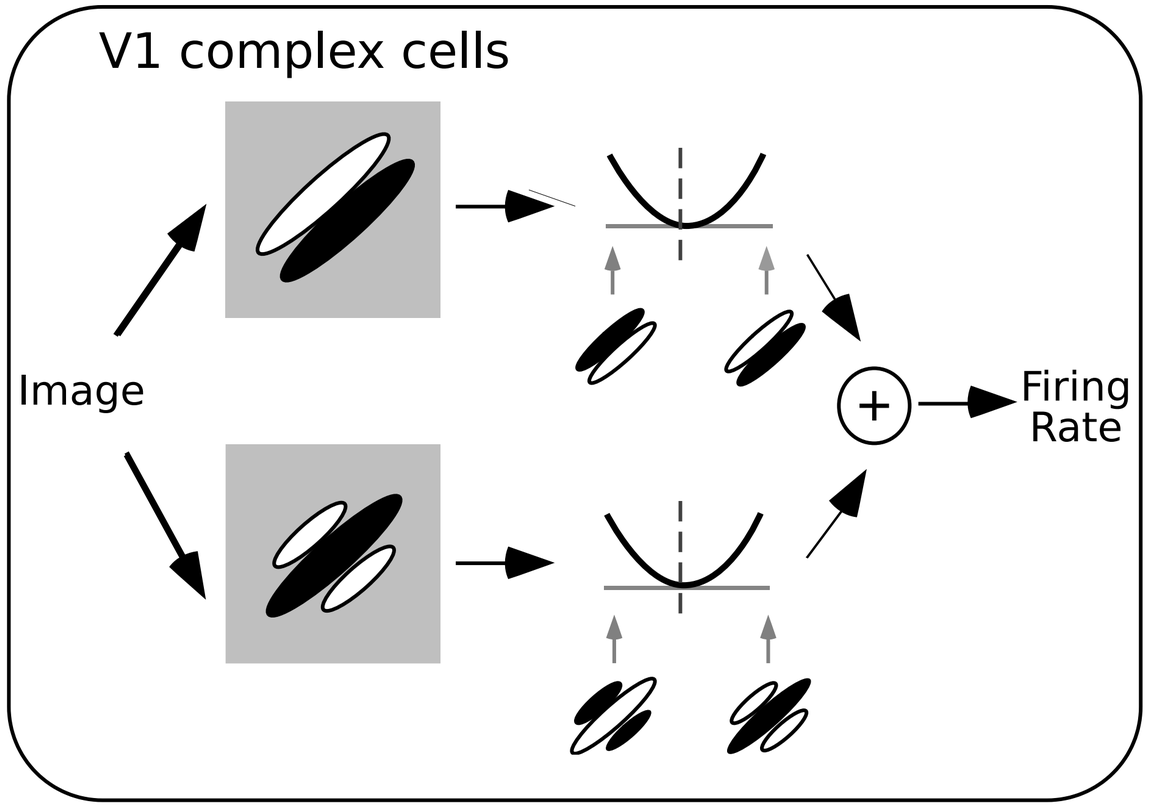




[Carandini et al, 2005]







[Carandini et al, 2005]

Outline

- fMRI
- Behavior

Outline

- fMRI: how does V1 spatial frequency tuning change across the visual field?

[Broderick, Simoncelli, and Winawer, J. Vis. 2021]

- Behavior: what information are humans insensitive to in their periphery?

Outline

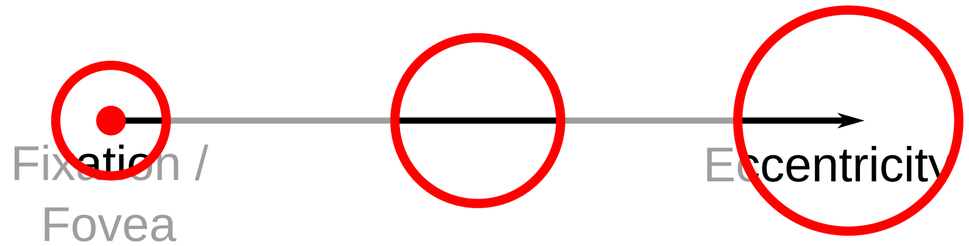
- fMRI: how does V1 spatial frequency tuning change across the visual field?

[Broderick, Simoncelli, and Winawer, J. Vis. 2021]

- Behavior: what information are humans insensitive to in their periphery?

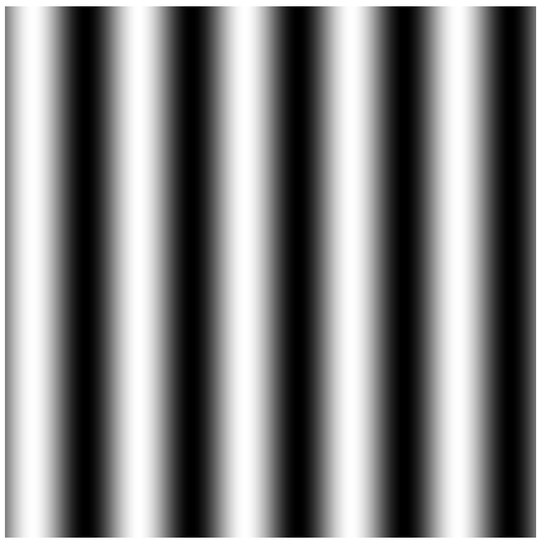
- Software: general implementations of algorithms to facilitate model testing and understanding

Perceptual ability is not uniform across the visual field

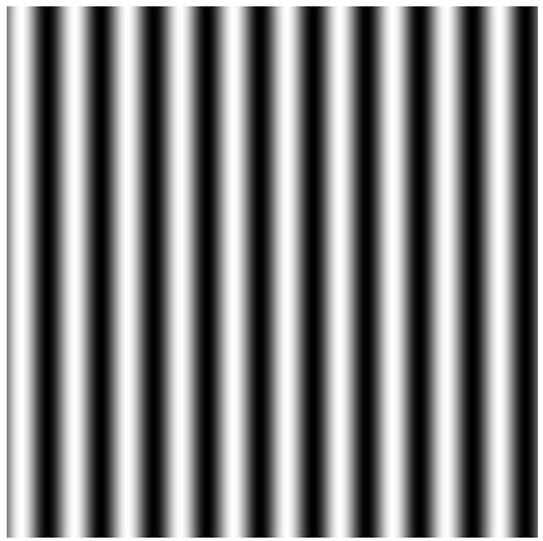


Spatial frequency

1 cycle / image

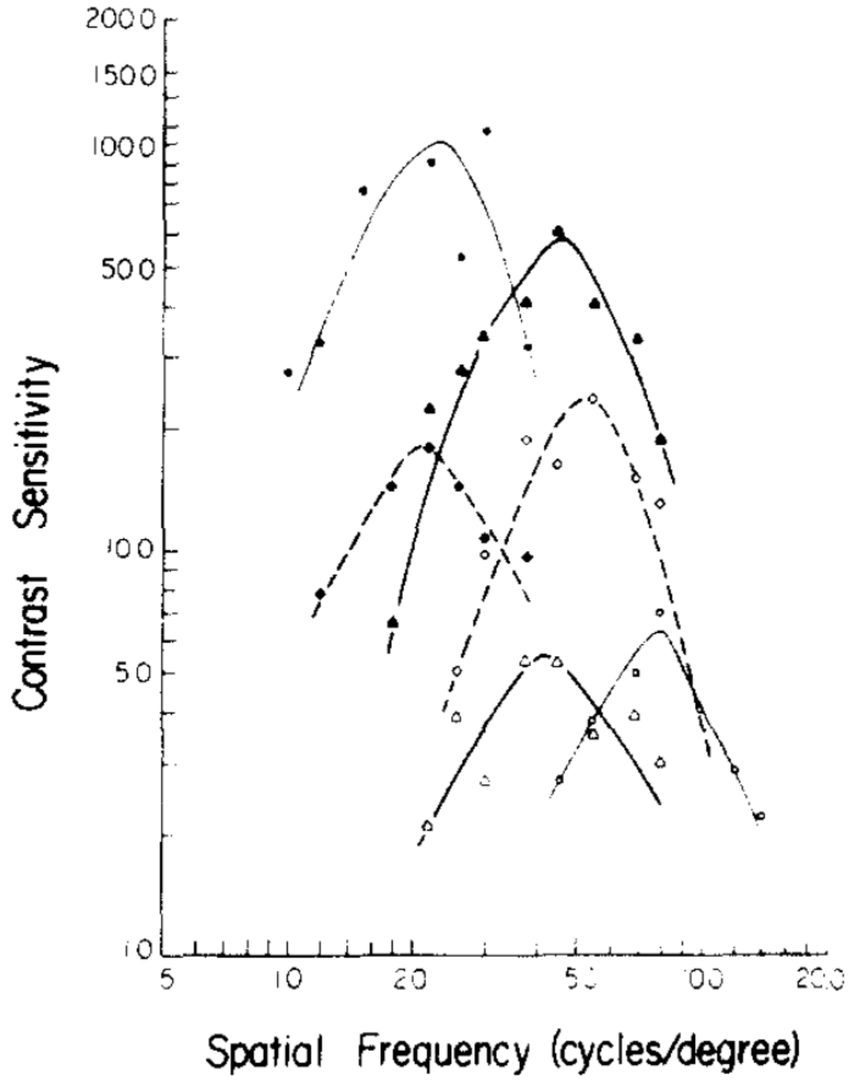


5 cycles / image



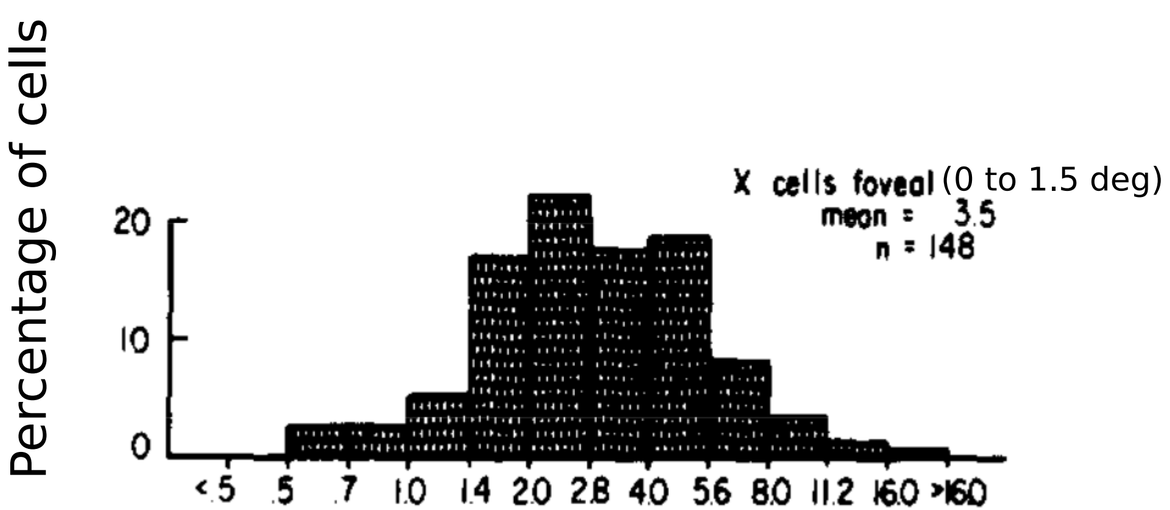
10 cycles / image

Macaque V1 neurons are tuned for spatial frequency



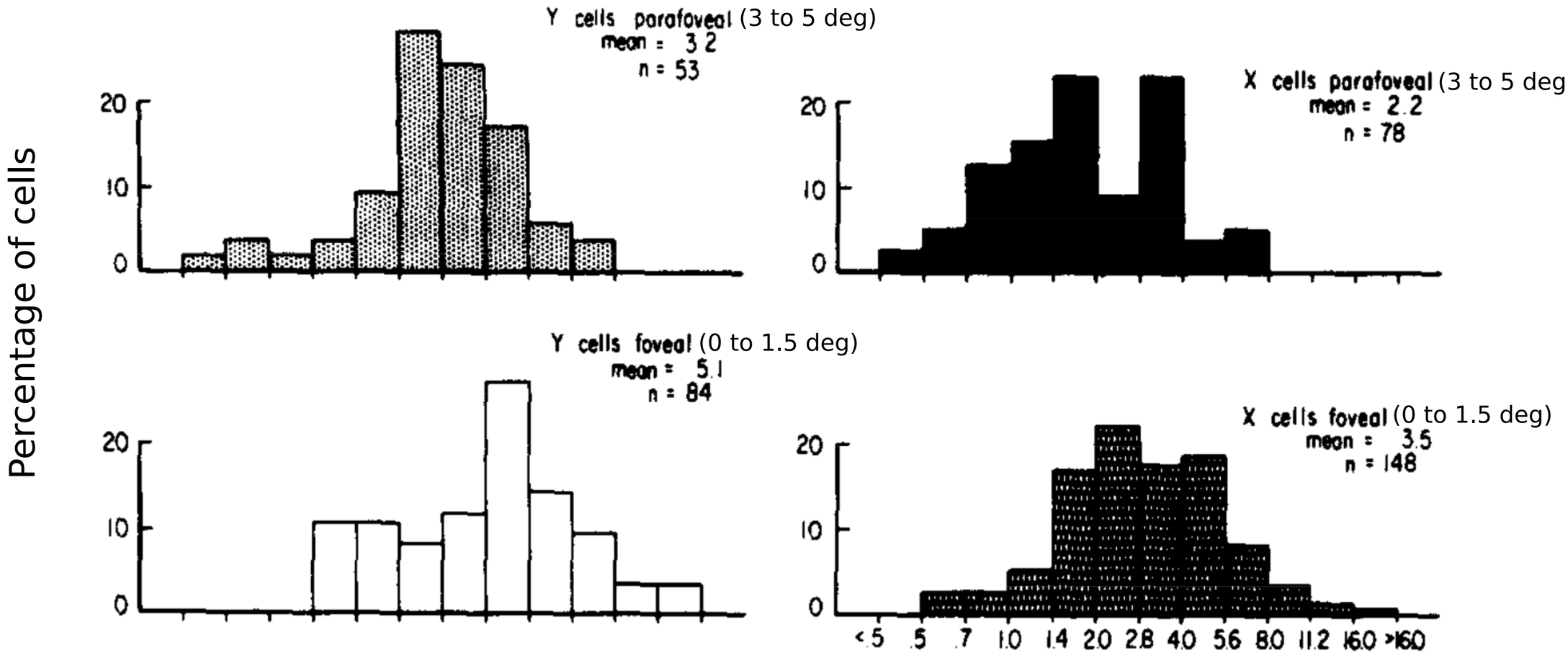
[De Valois et al., 1982]

Macaque V1 neurons are tuned for spatial frequency



[De Valois et al., 1982]

This tuning changes with eccentricity



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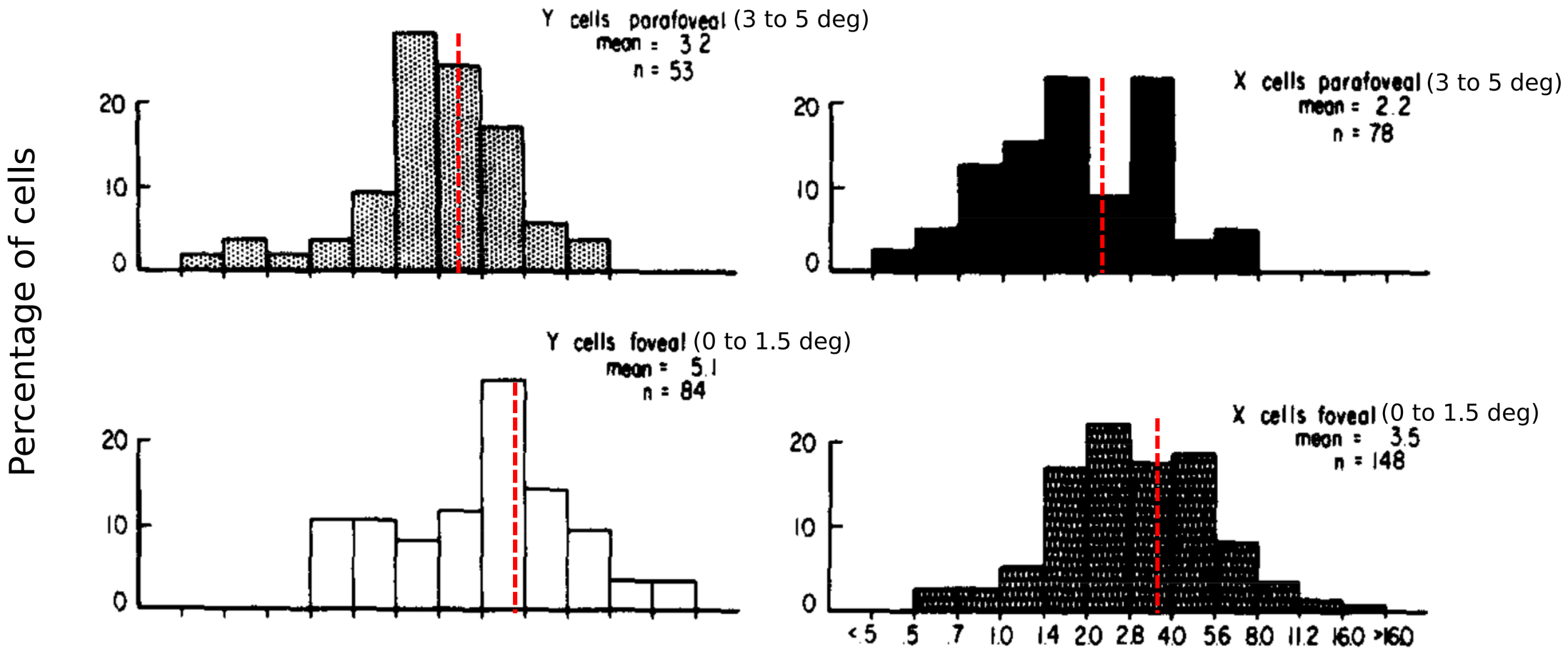

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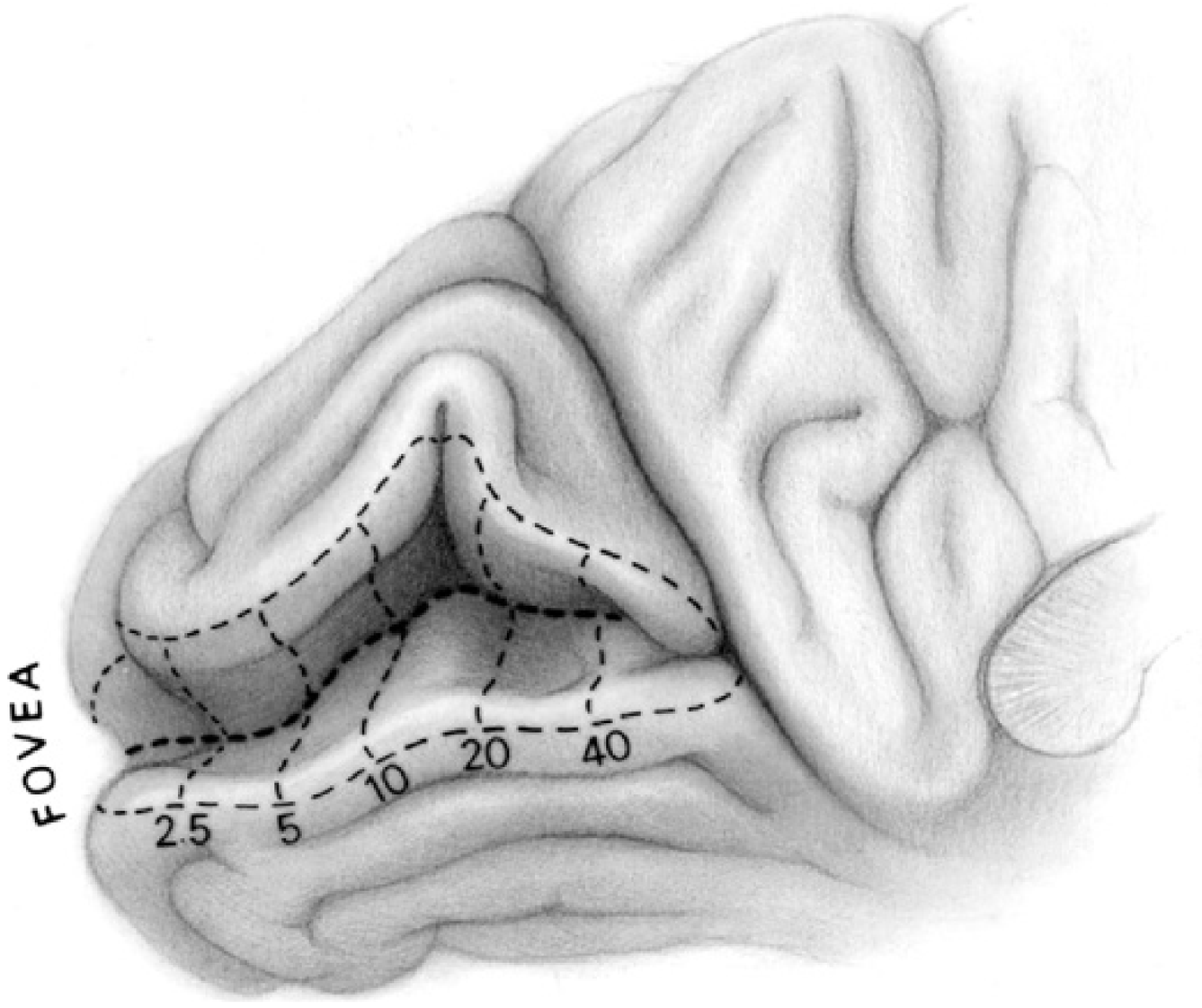
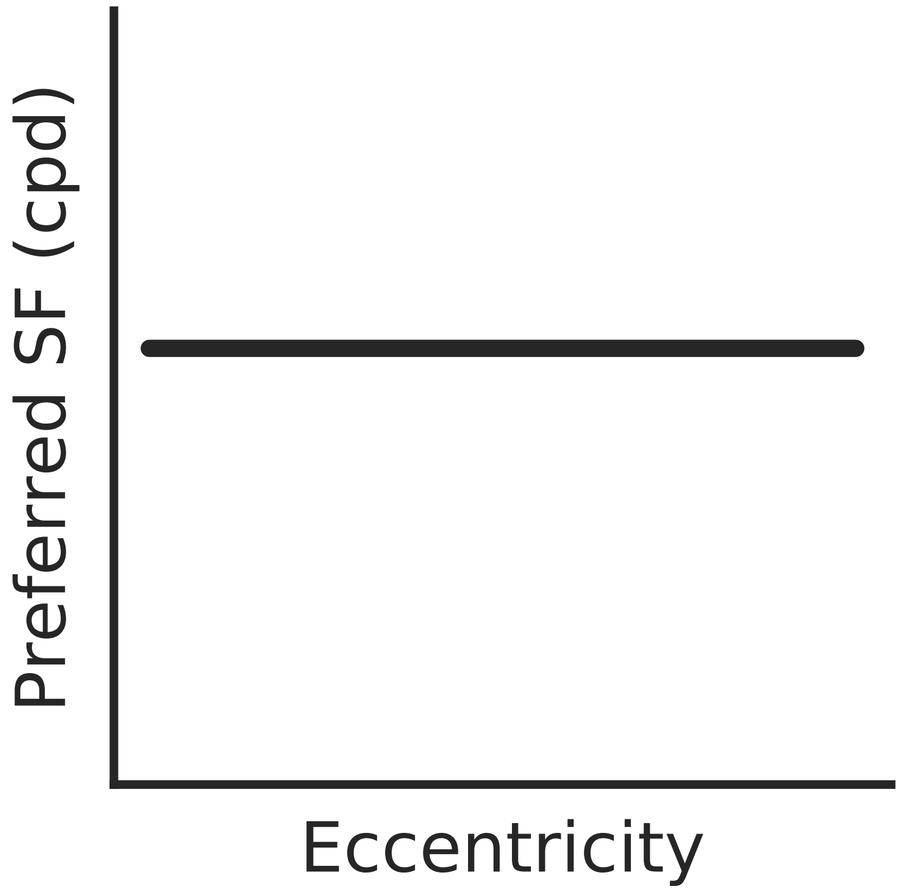
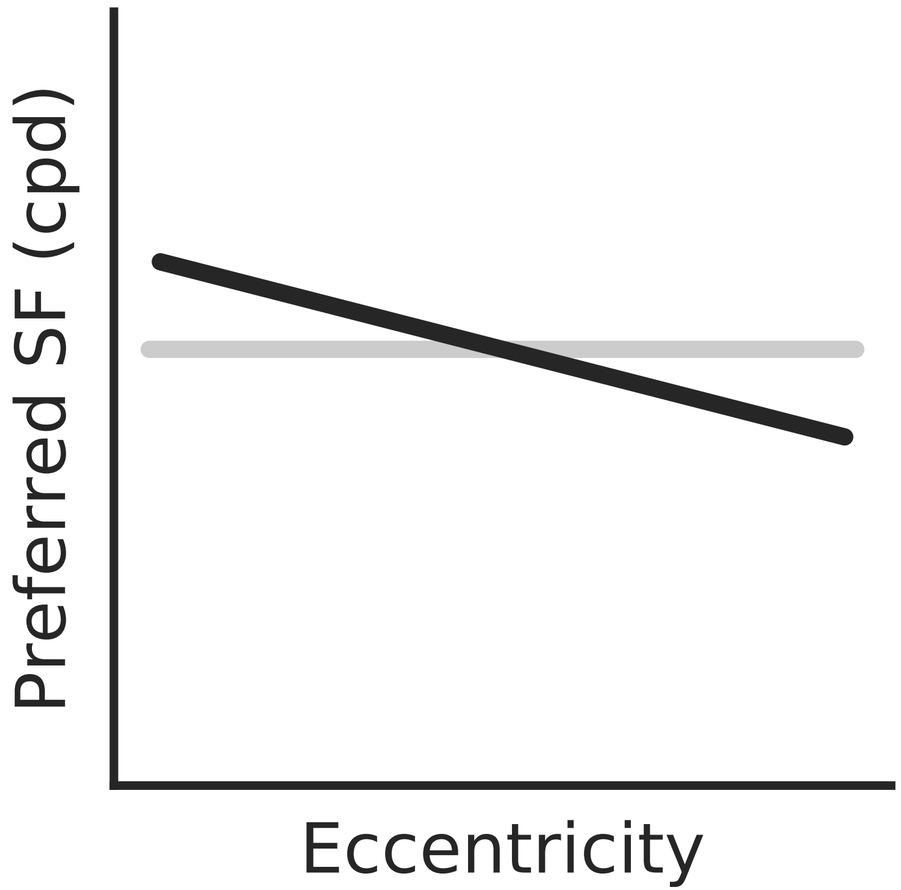


[Horton and Hoyt, 1991]

"a dismaying exercise in tedium, like trying to cut the back lawn with a pair of nail scissors"

— Hubel and Wiesel, 1977


Preferred SF (cpd)
Eccentricity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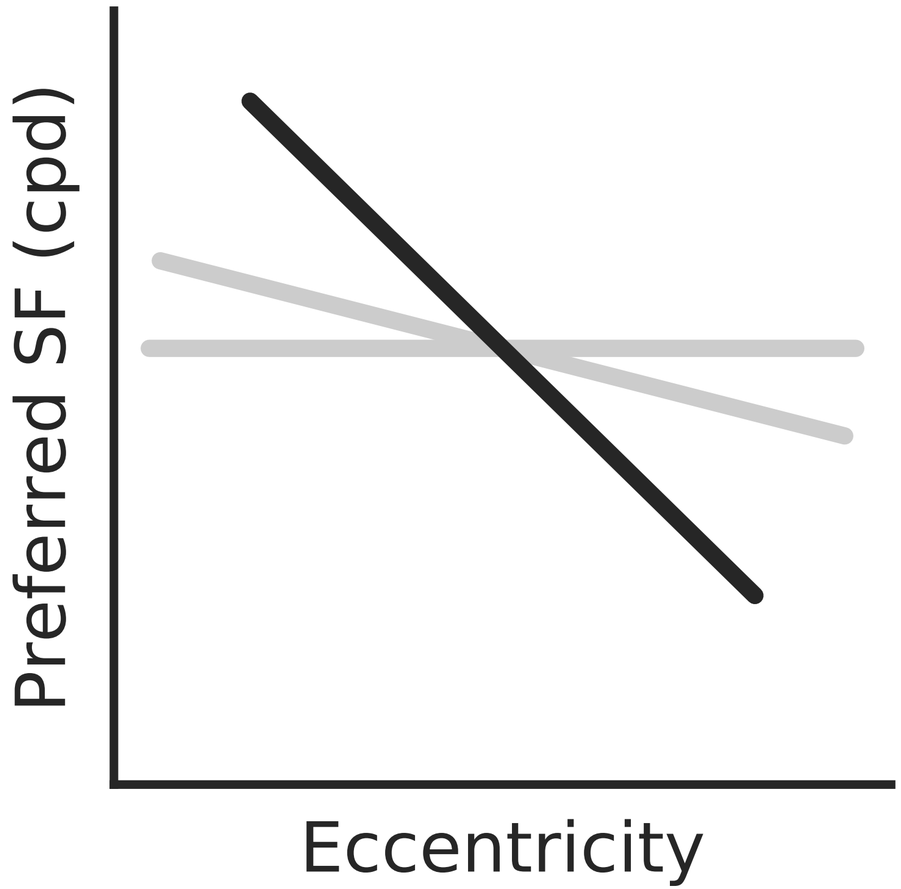
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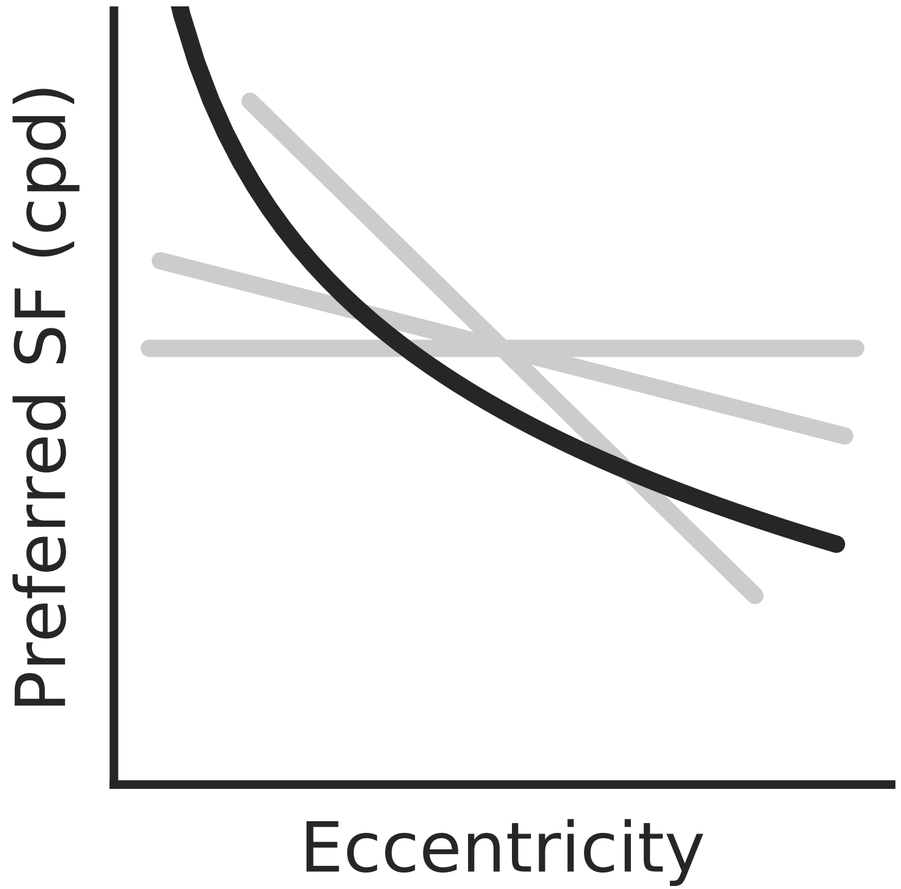
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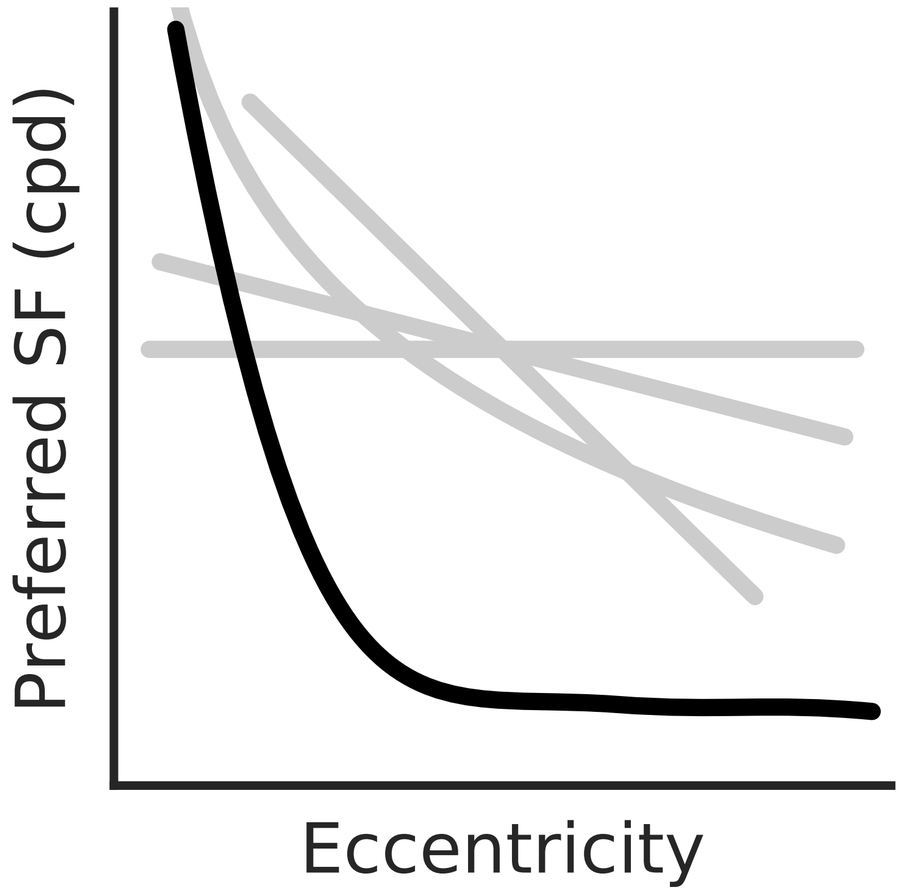
Preferred SF (cpd)
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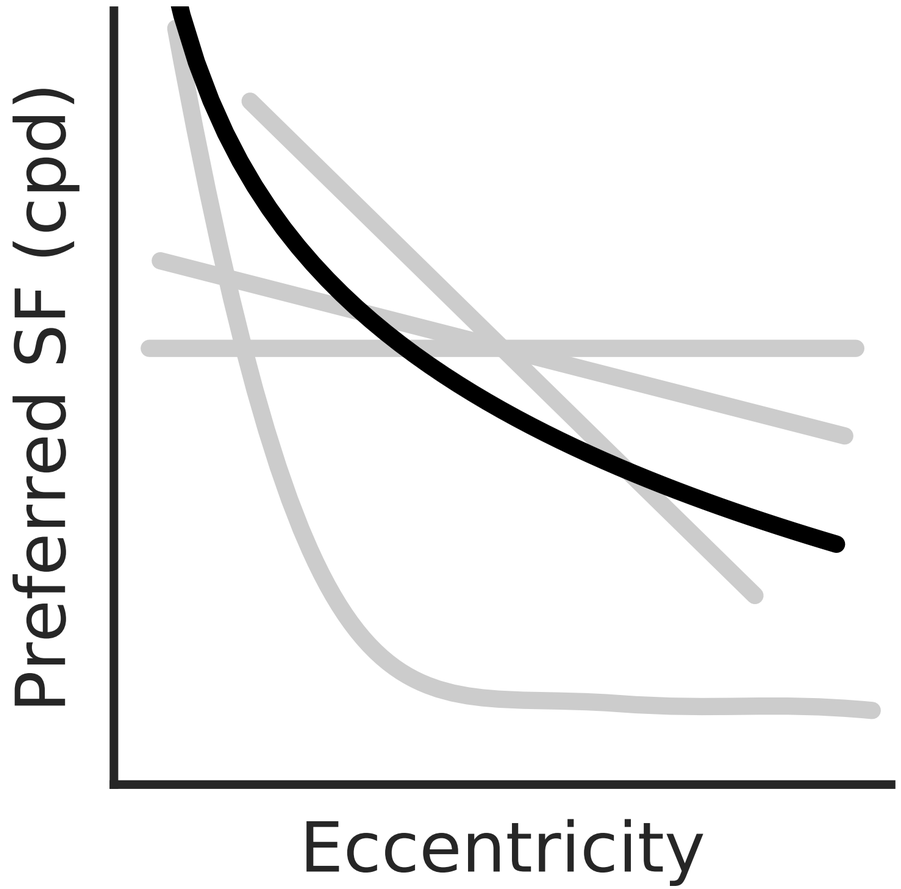
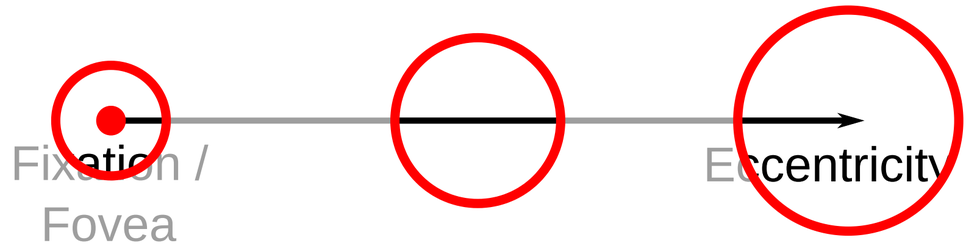
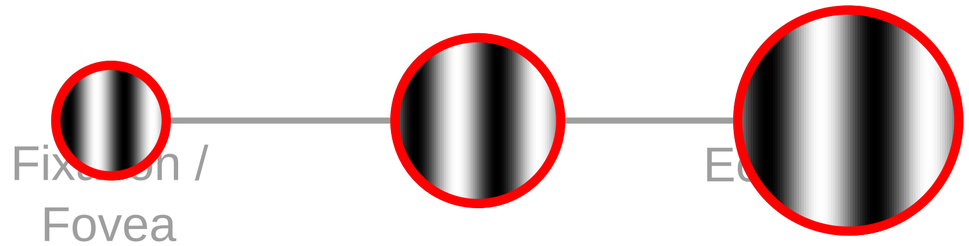
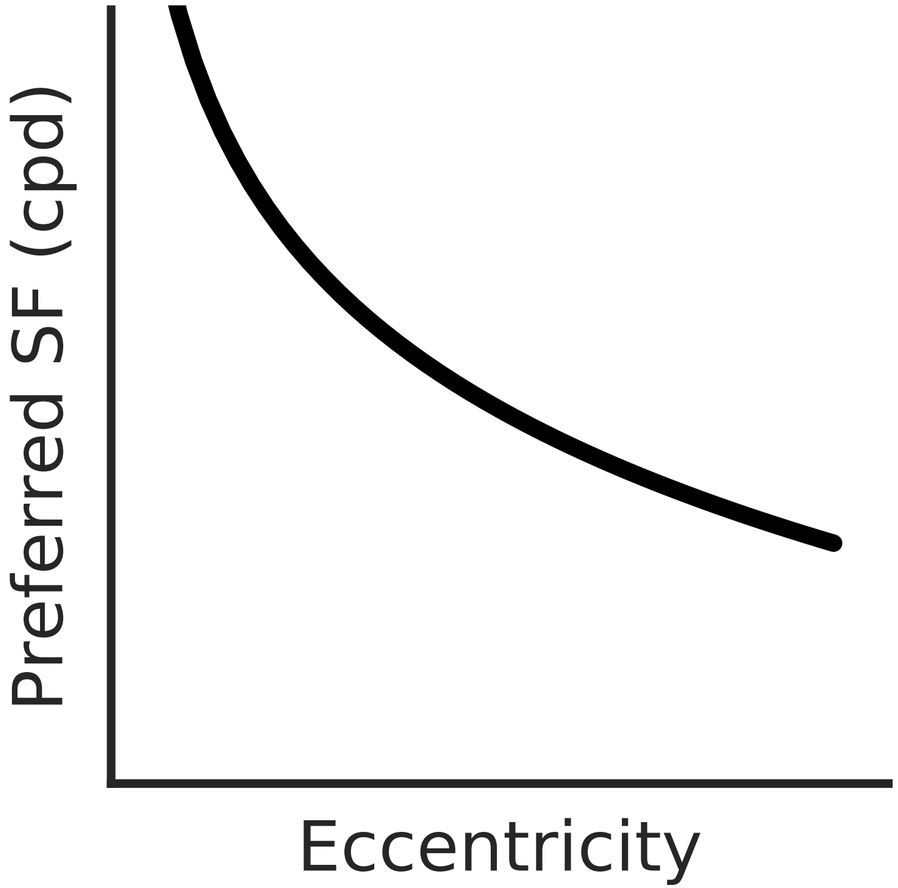

Preferred SF (cpd)
Eccentricity

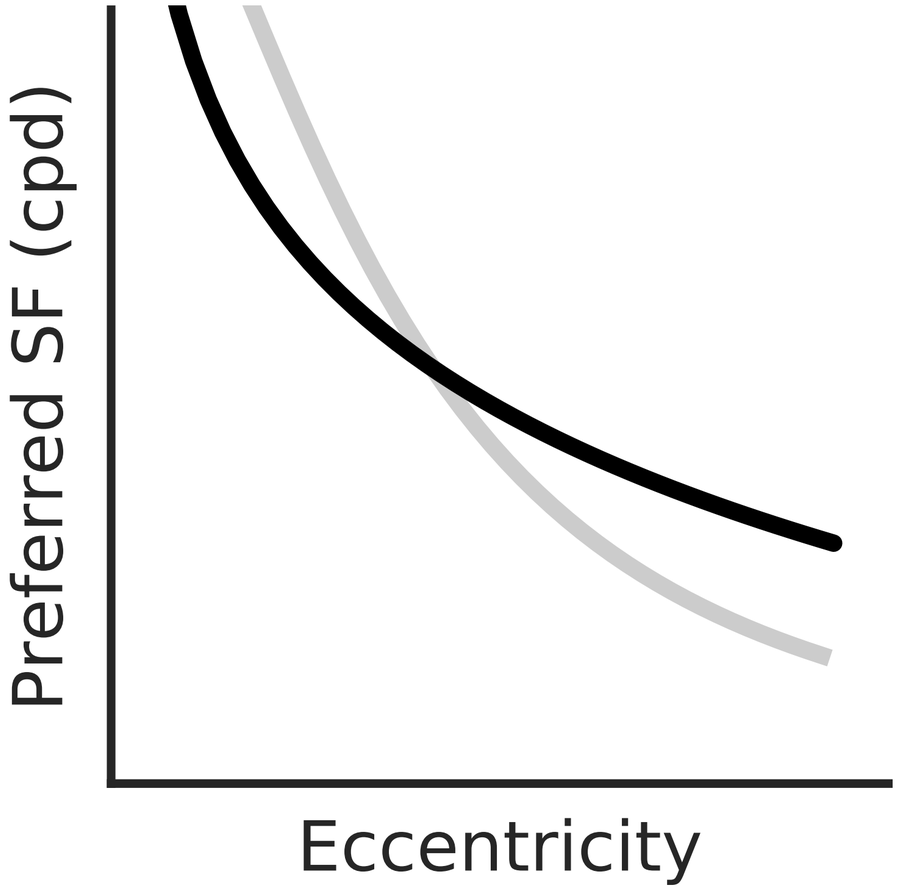
Perceptual ability is not uniform across the visual field

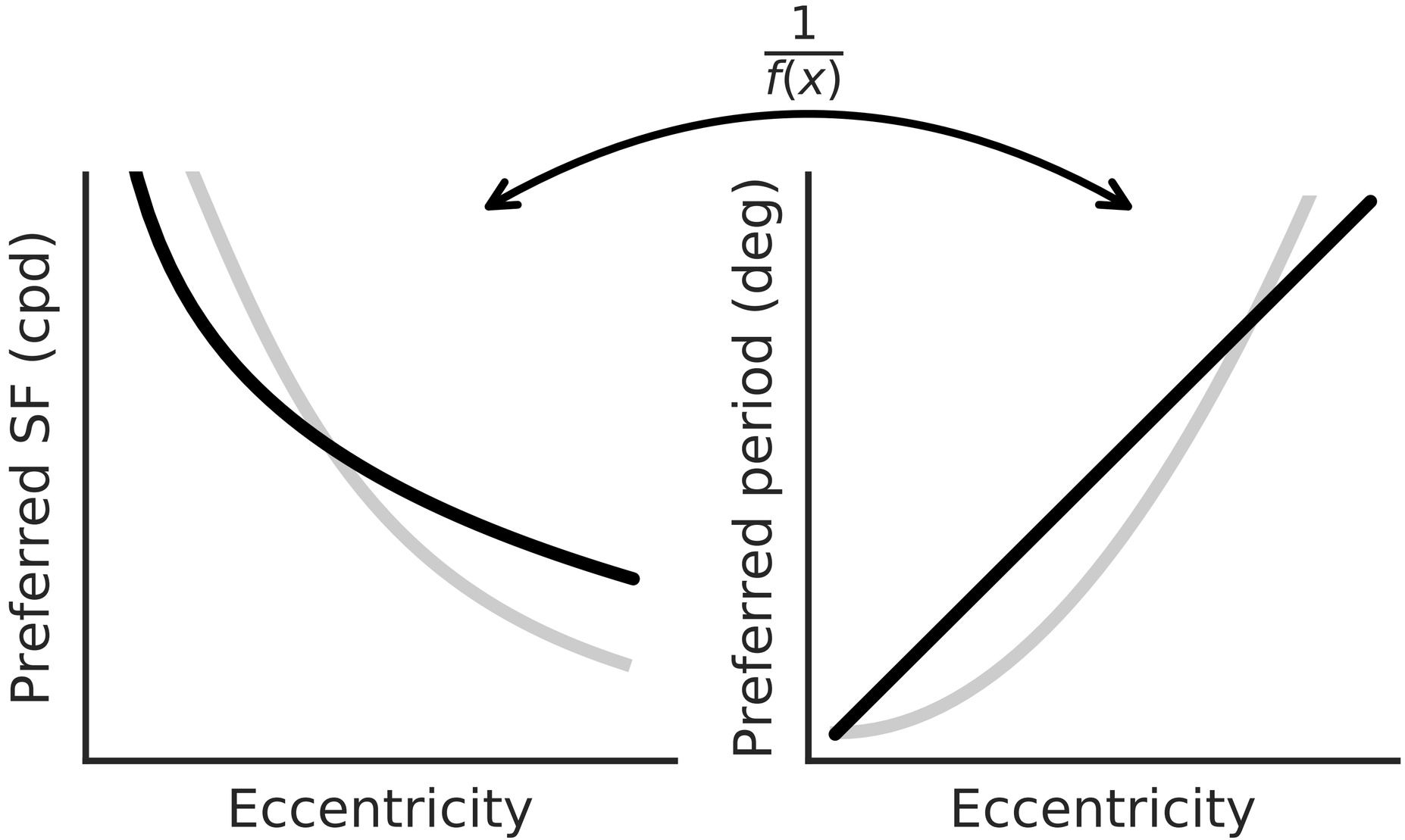


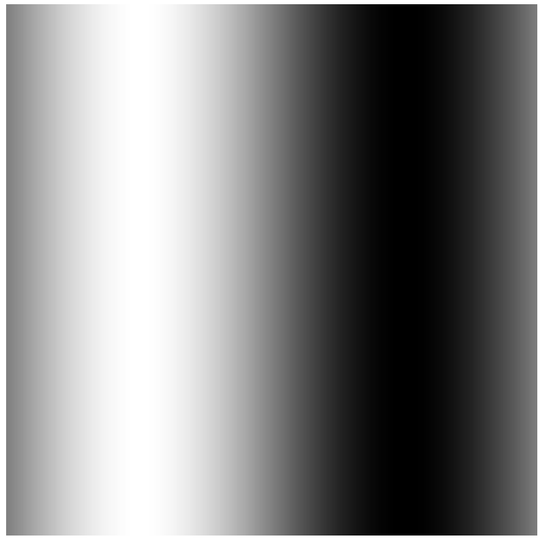
Perceptual ability is not uniform across the visual field



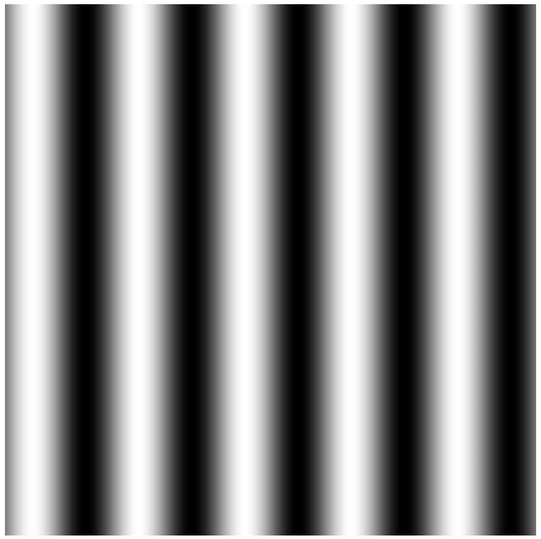

Preferred SF (cpd)
Eccentricity


Preferred SF (cpd)
Eccentricity

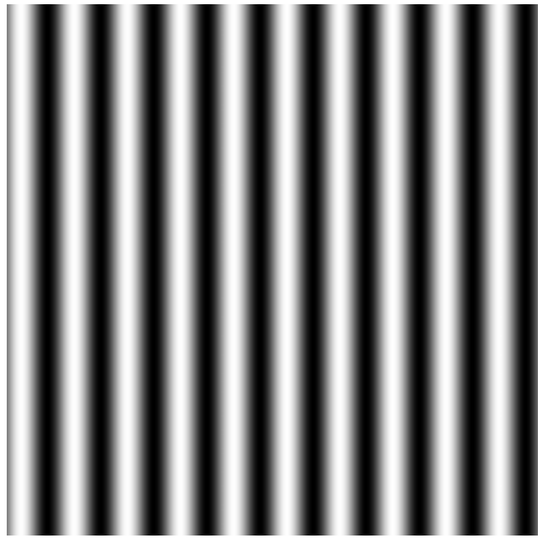

1
f(x)
Preferred SF (cpd)
Eccentricity
Preferred period (deg)
Eccentricity



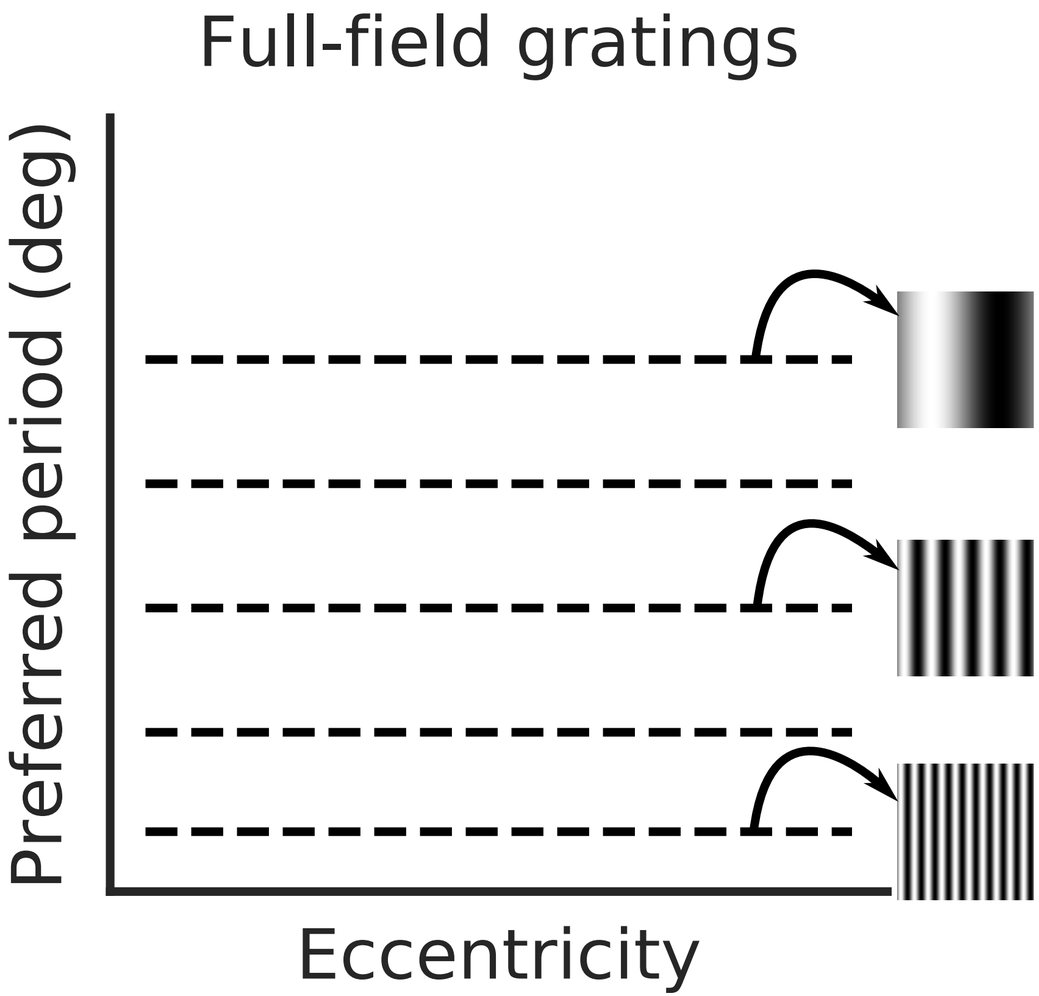
1 cycle / image

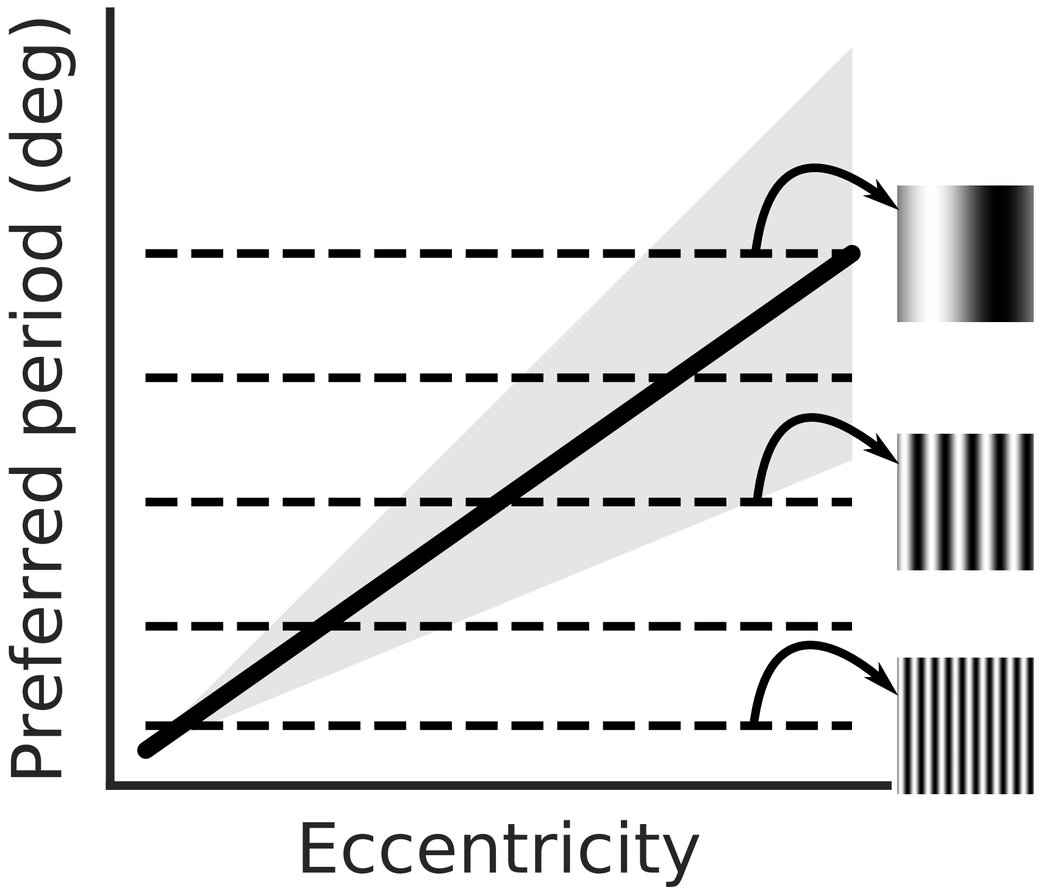


5 cycles / image

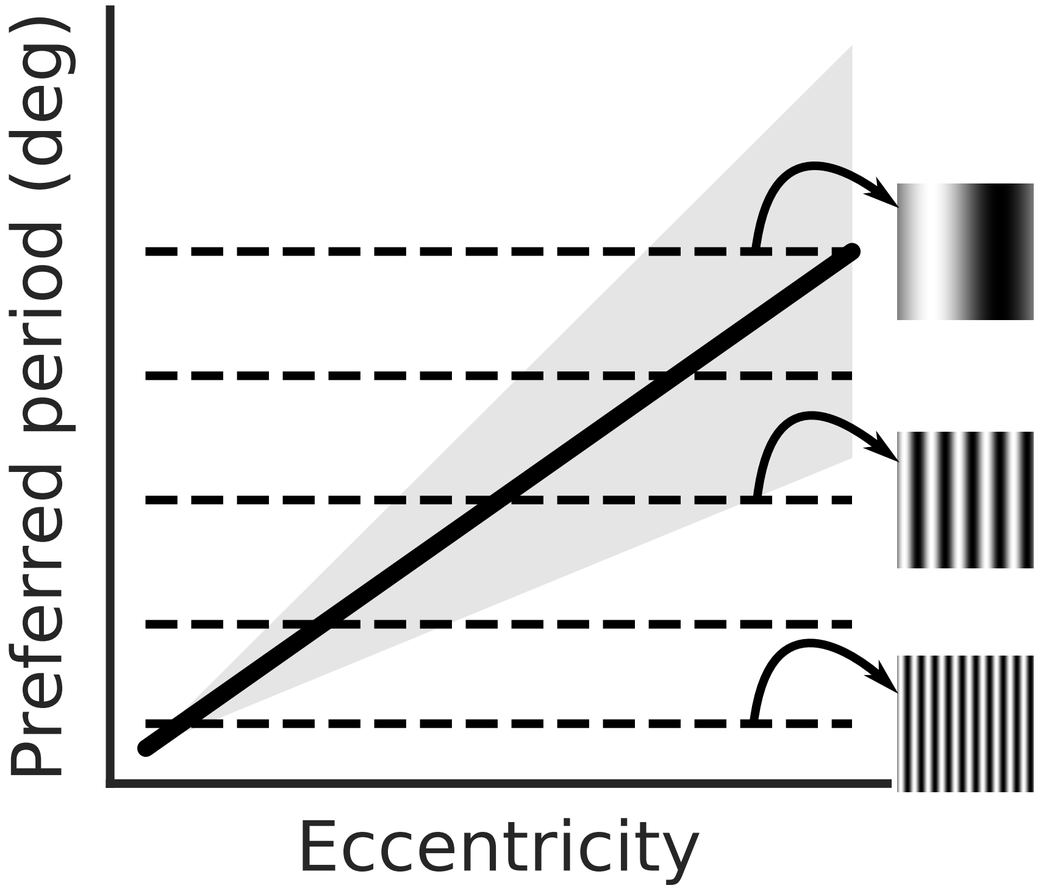


10 cycles / image

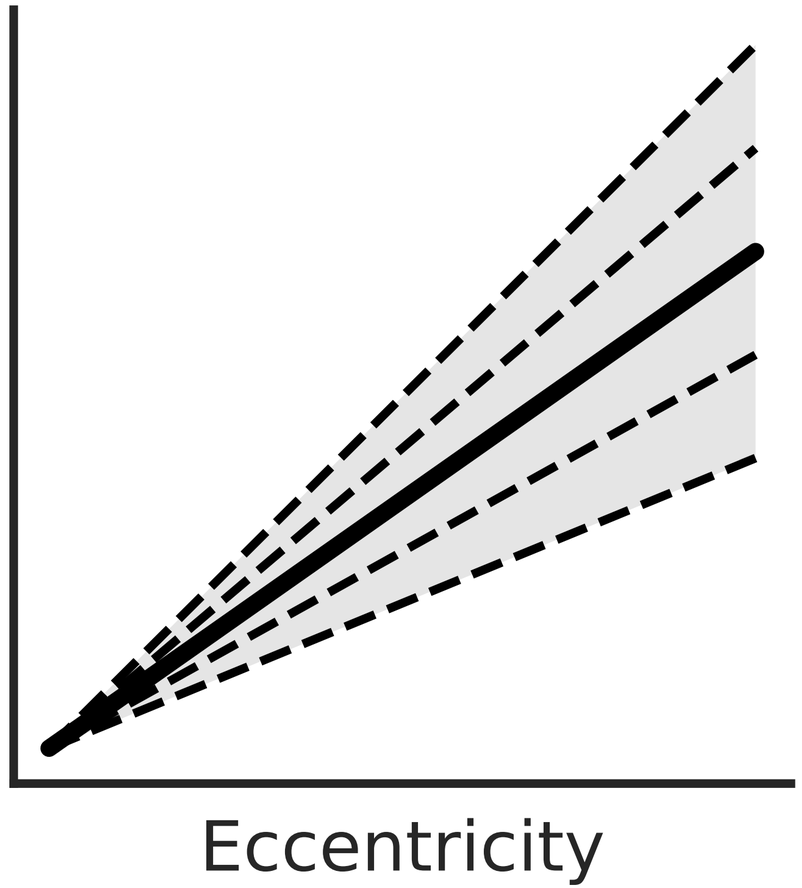

Full-field gratings
Preferred period (deg)
Eccentricity


Full-field gratings
Preferred period (deg)
Eccentricity

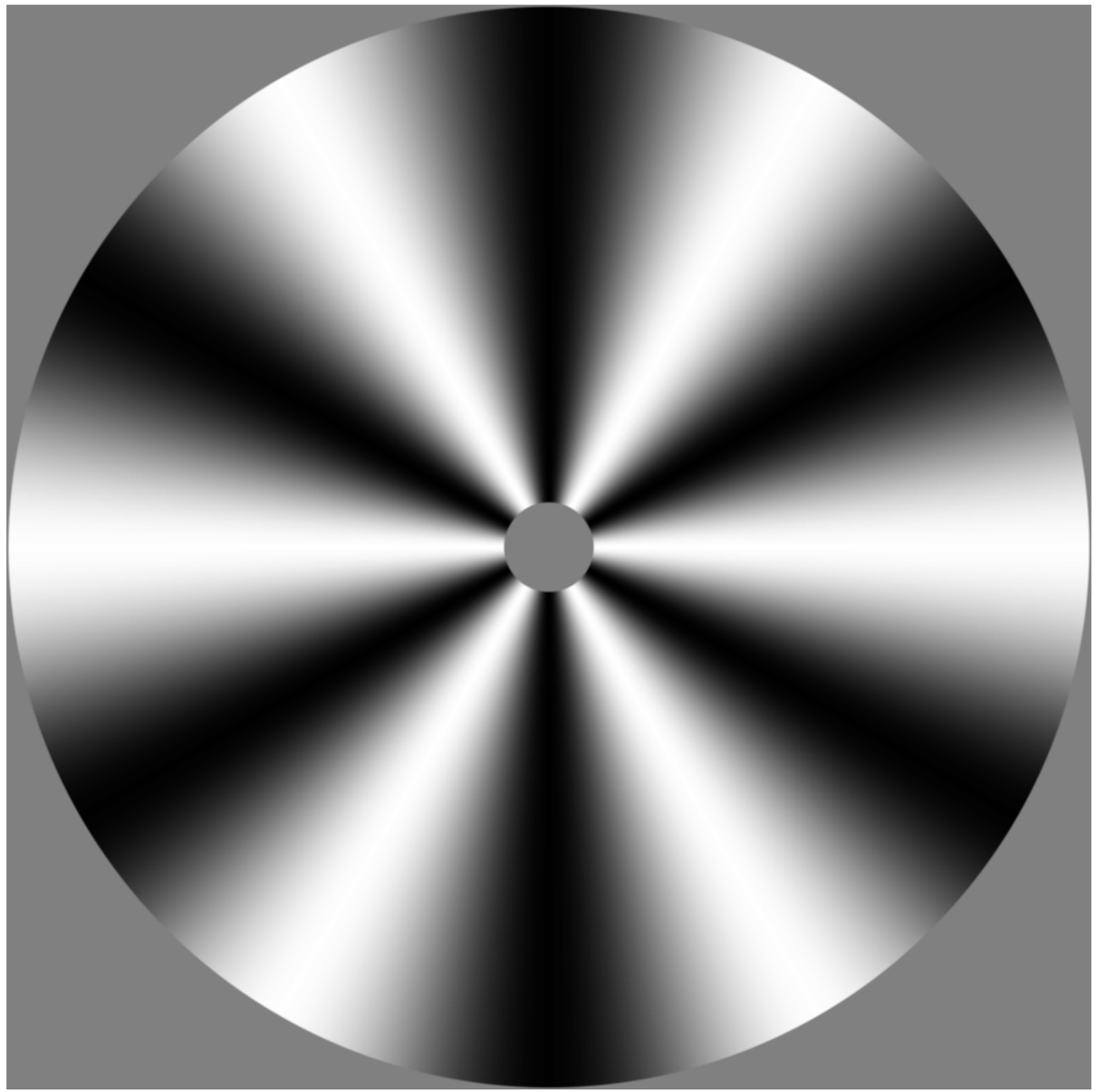
Full-field gratings



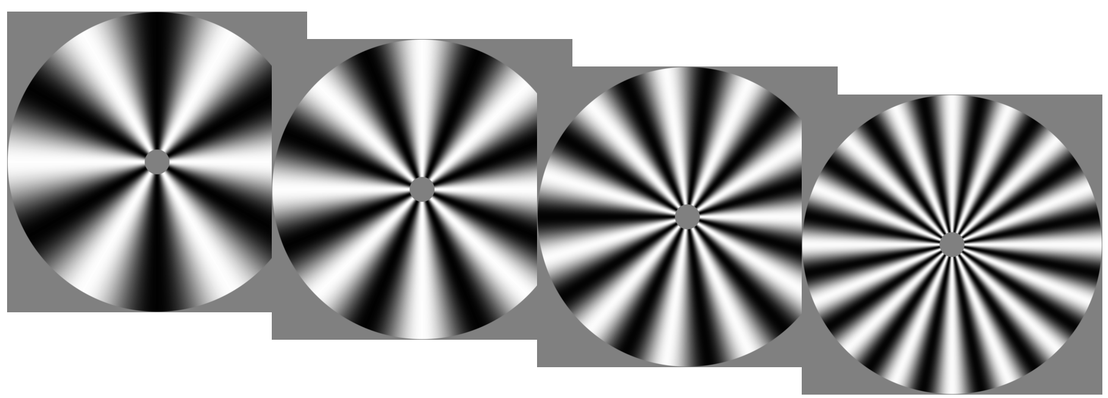
Scaled gratings



Stimulus period grows linearly with eccentricity



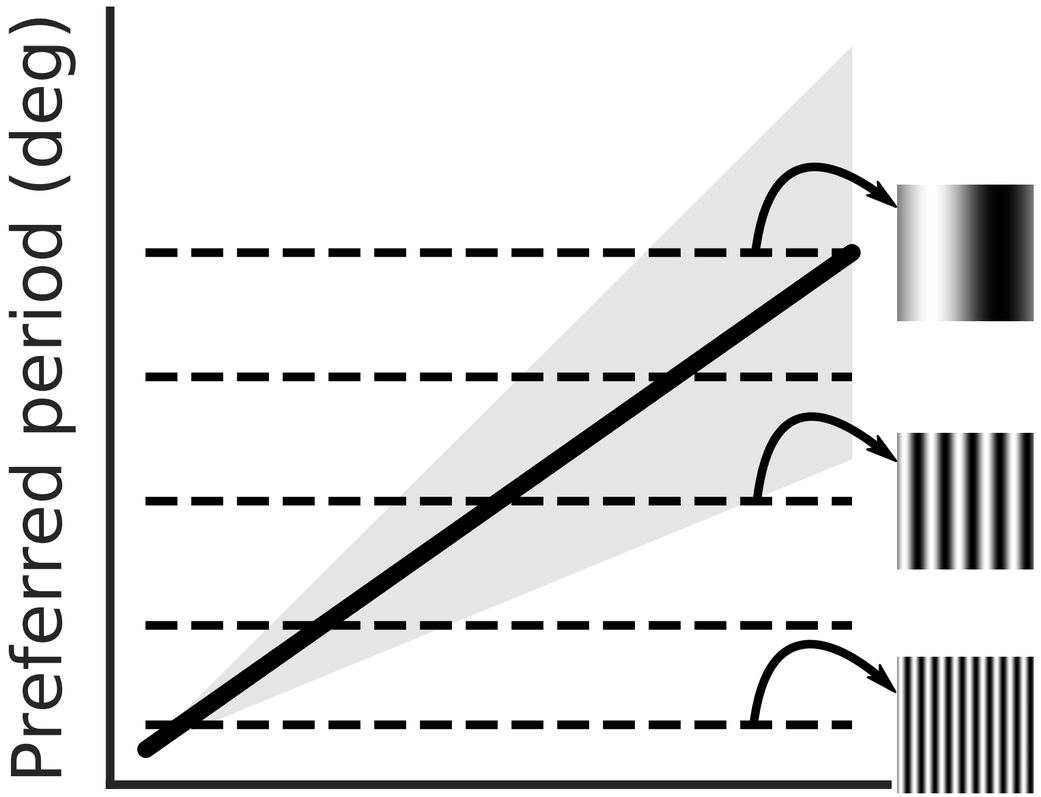
Stimuli span a wide range of eccentricities



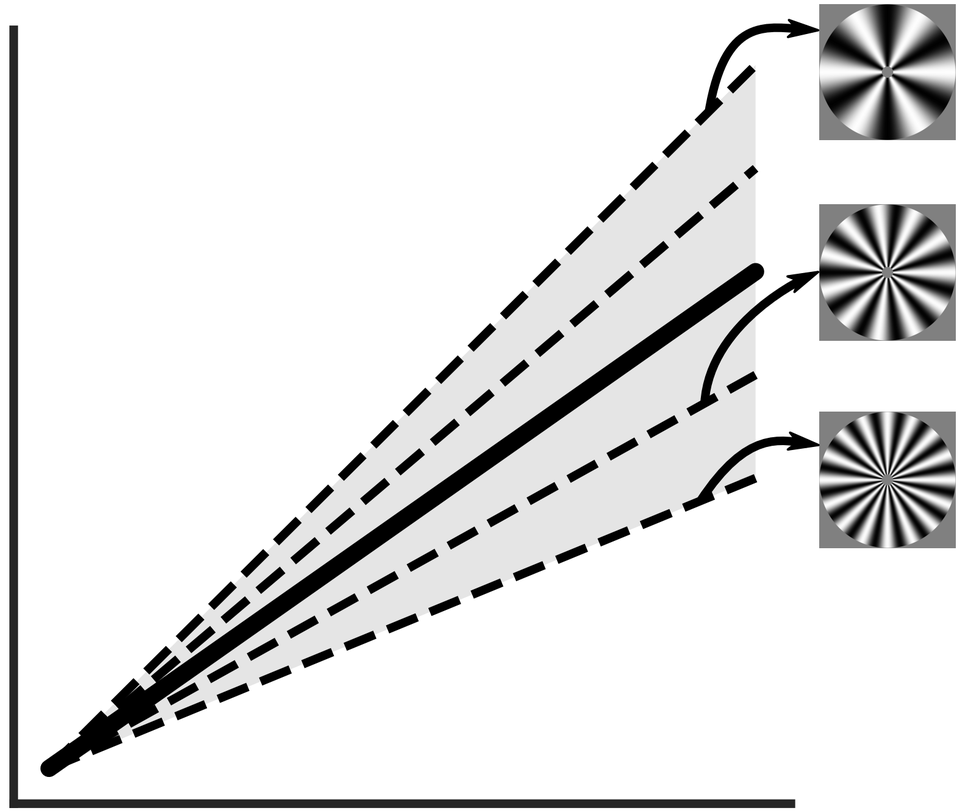
Increasing base frequency

Stimuli span a wide range of eccentricities

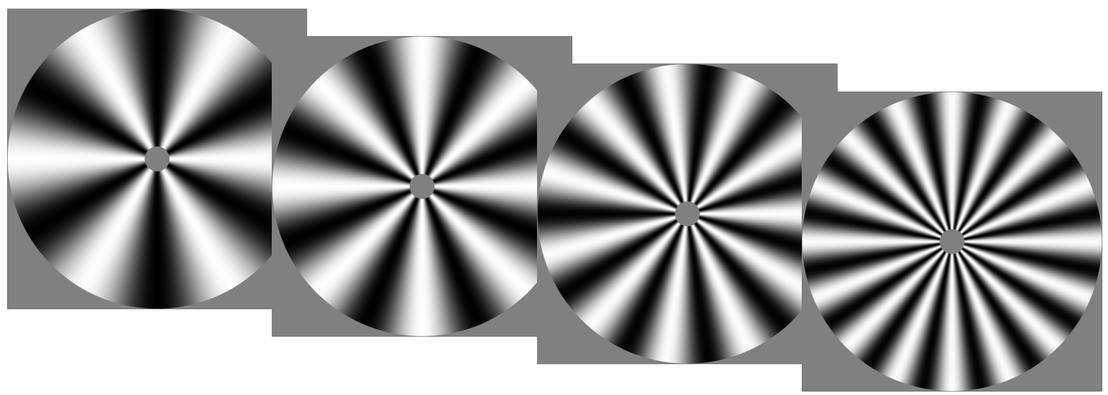
Full-field gratings

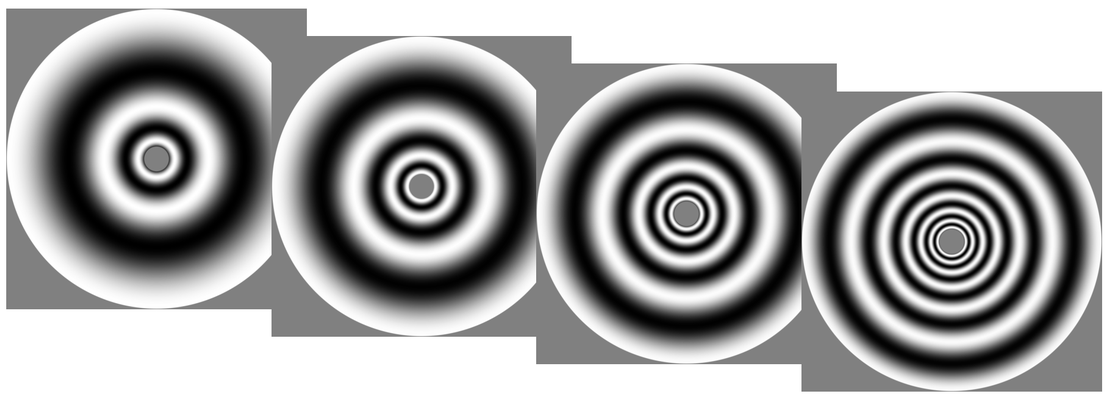


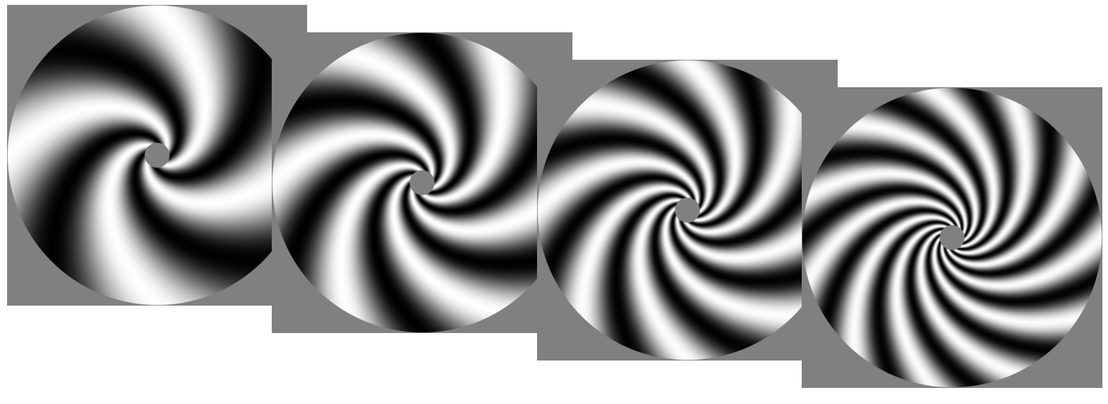
Scaled gratings

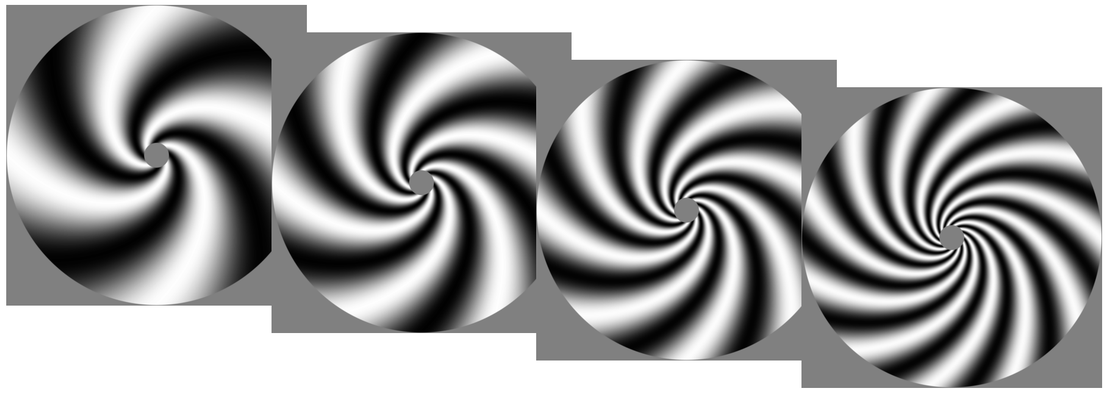


... and orientations

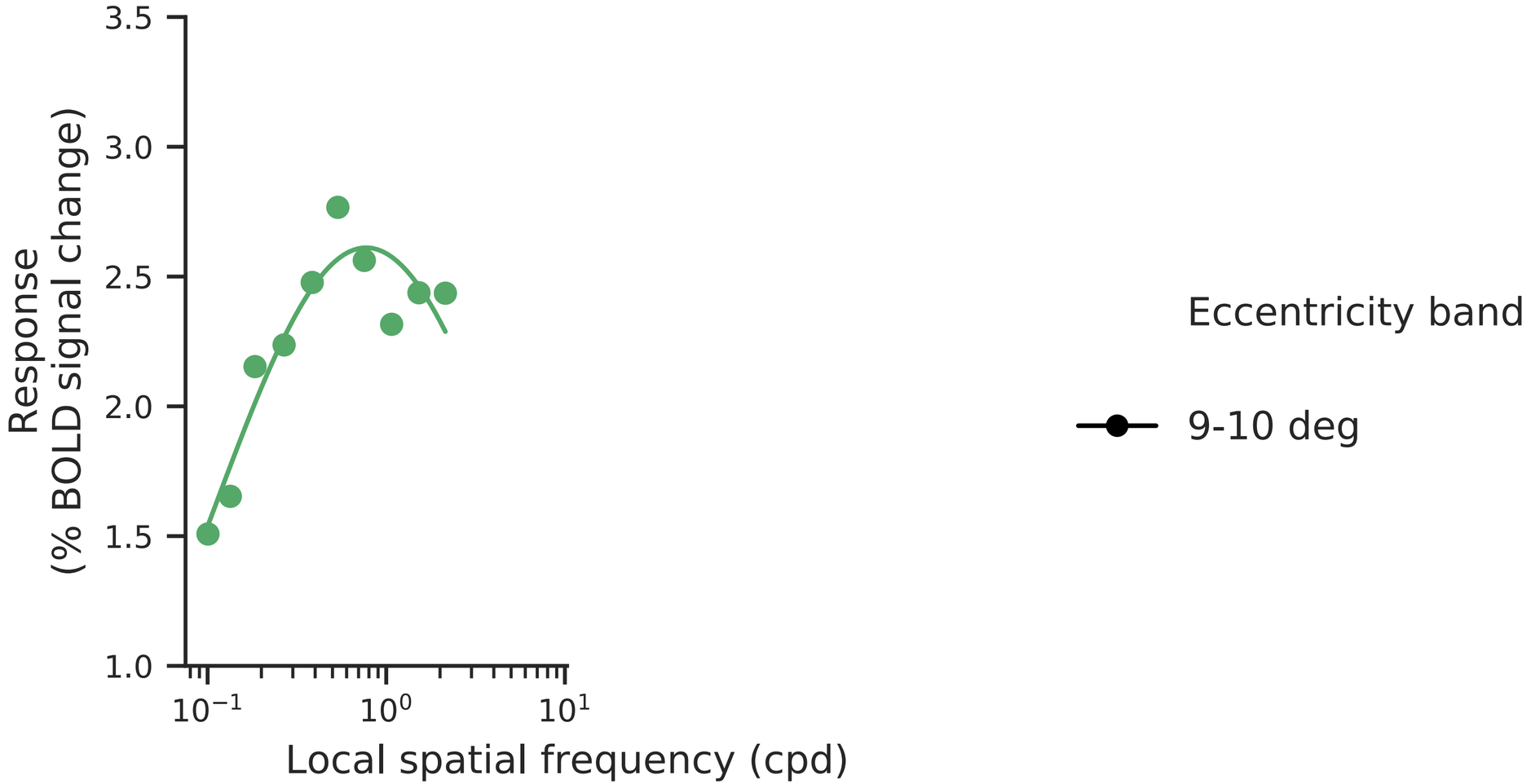




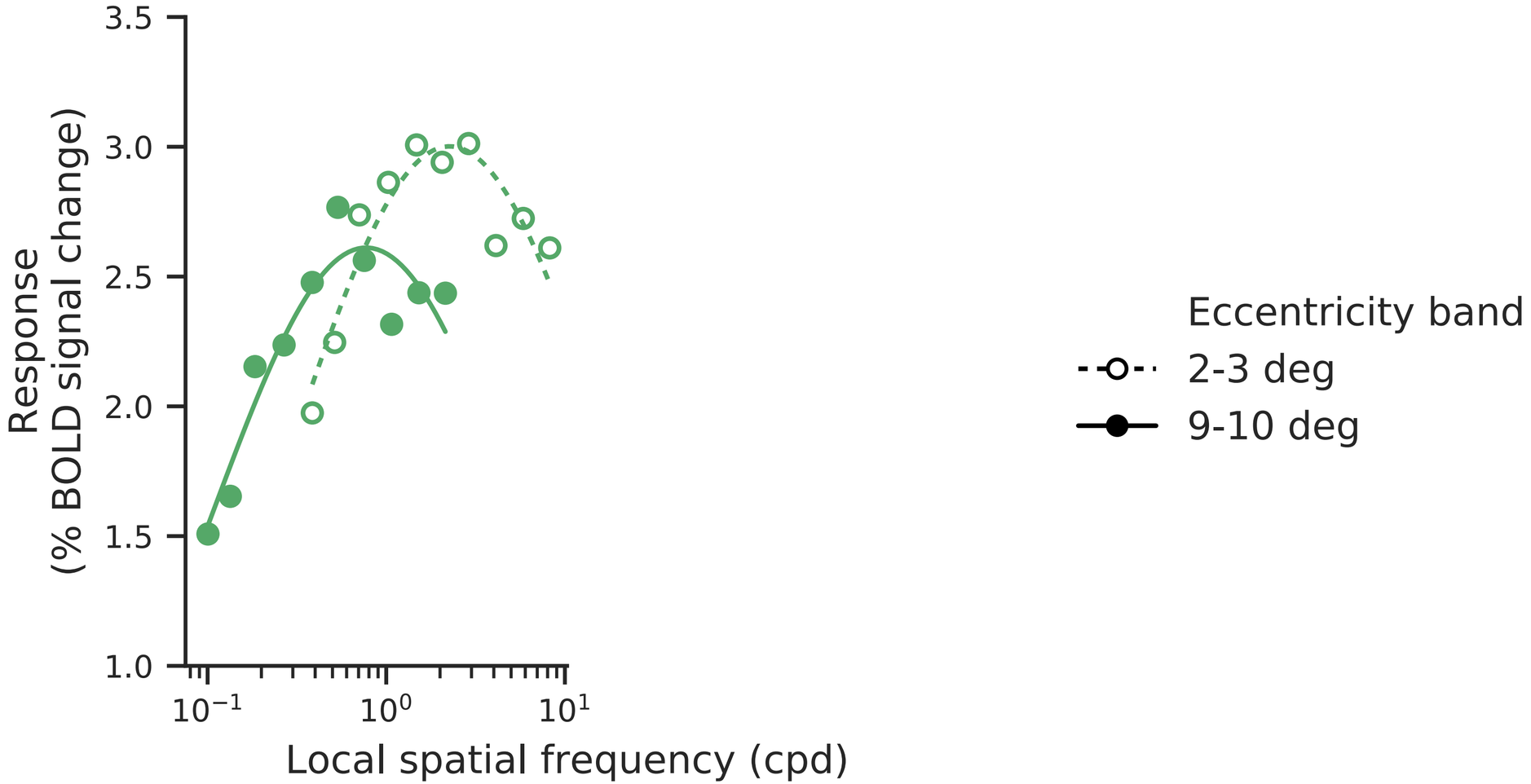




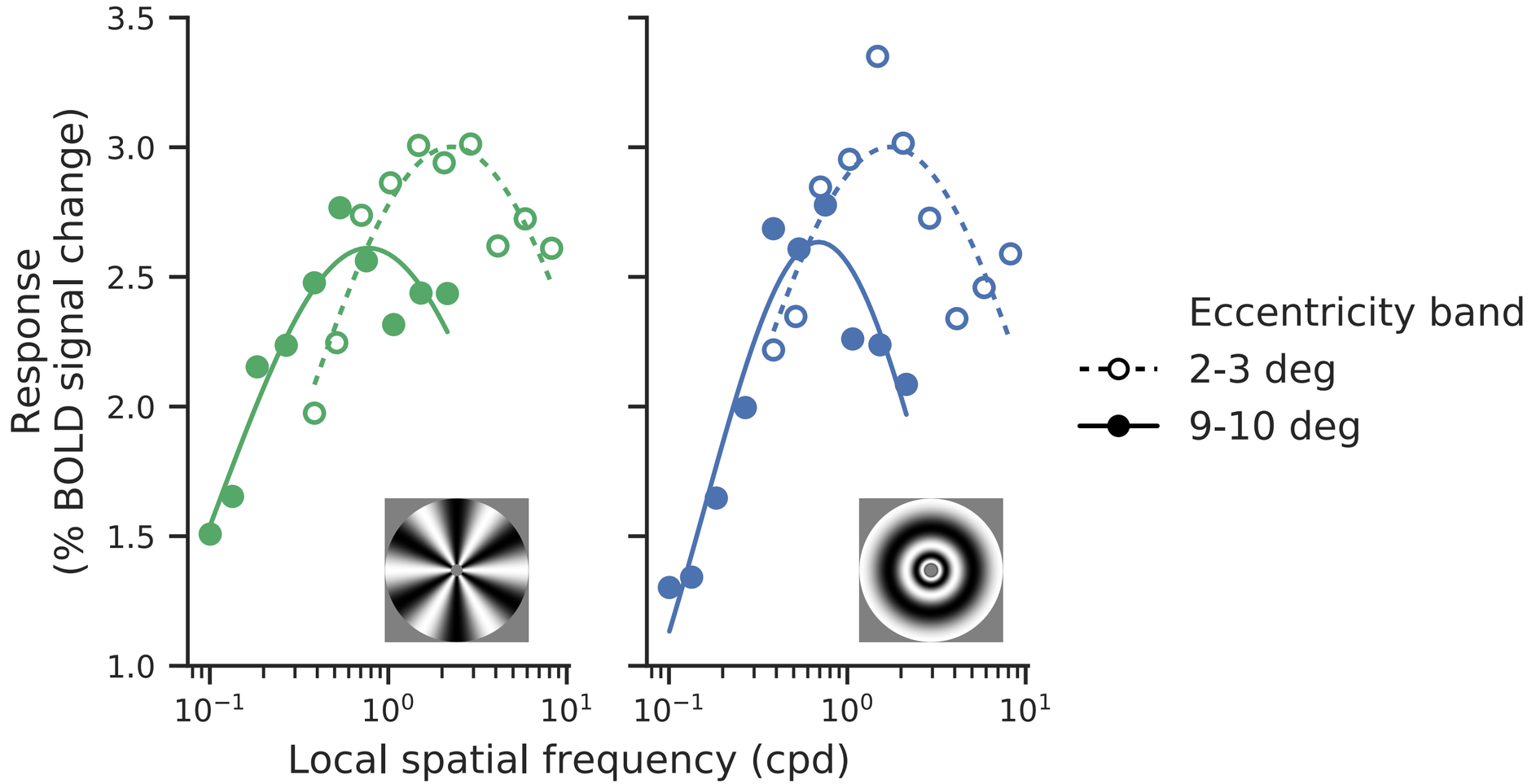
fMRI responses are tuned for spatial frequency

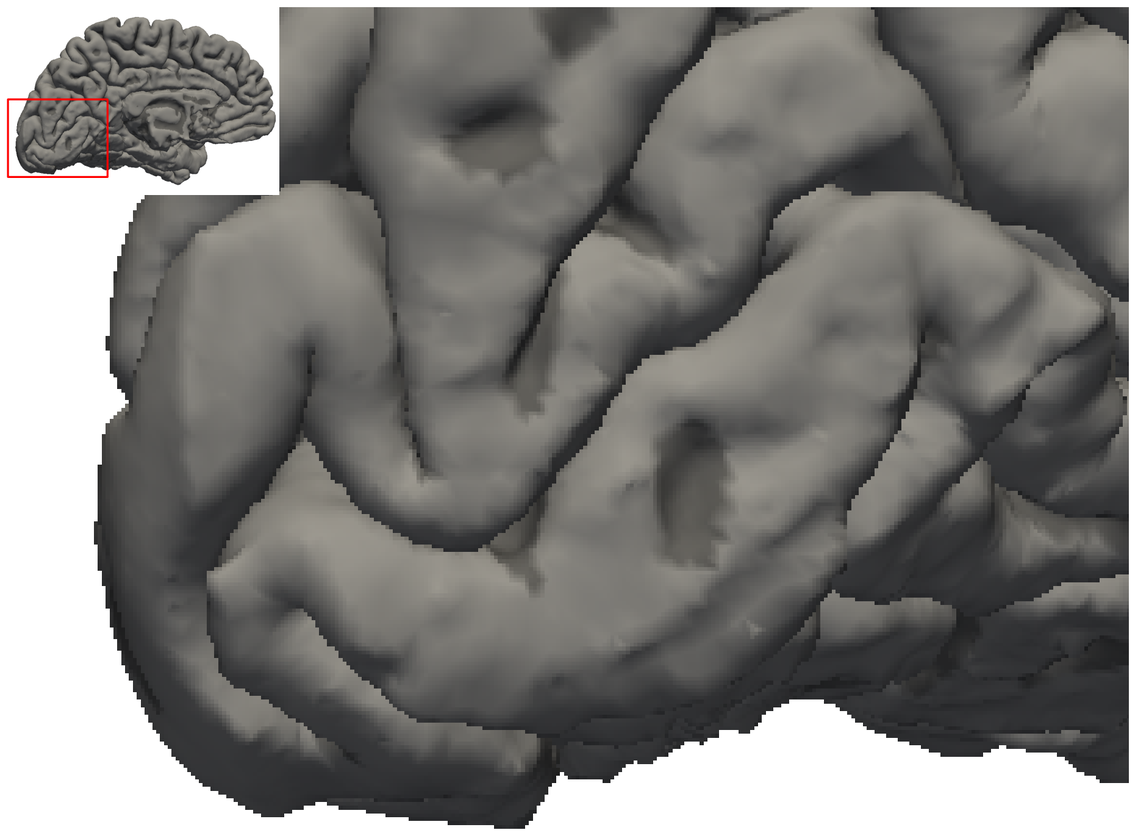


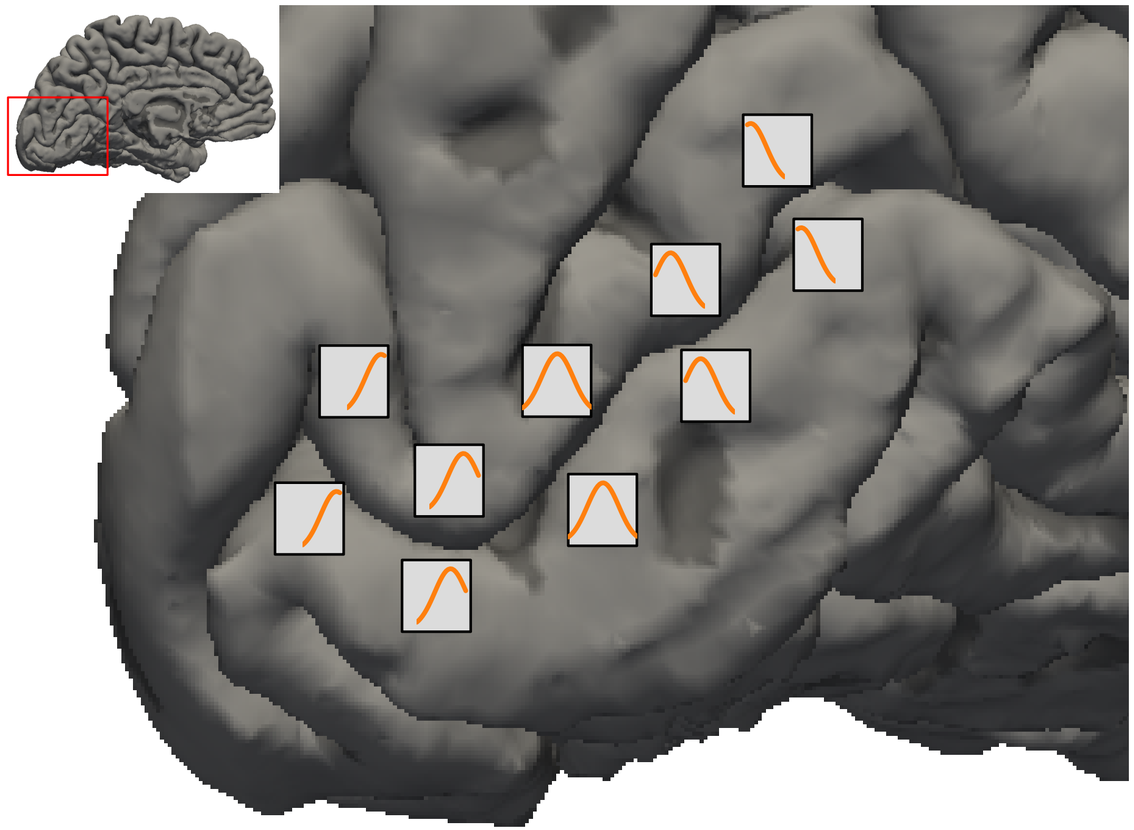
Peak spatial frequency gets higher as eccentricity drops

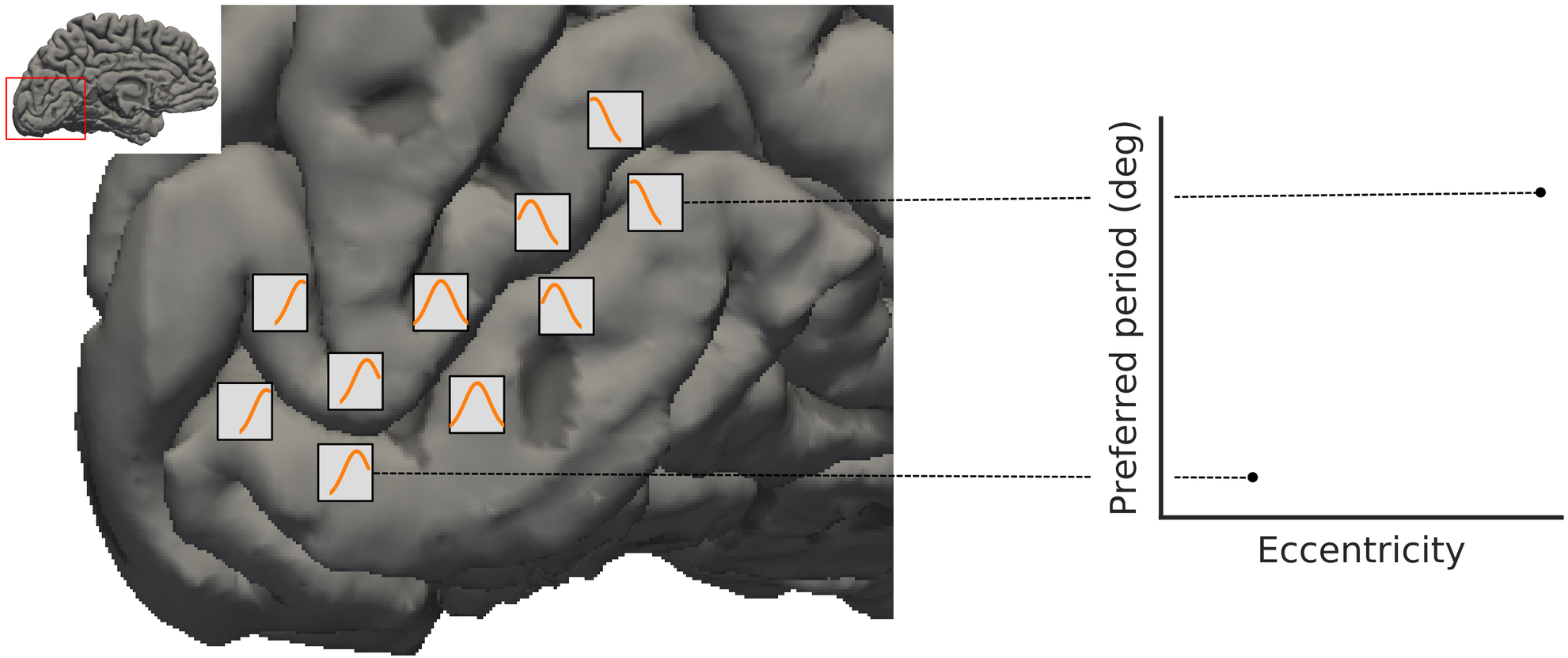


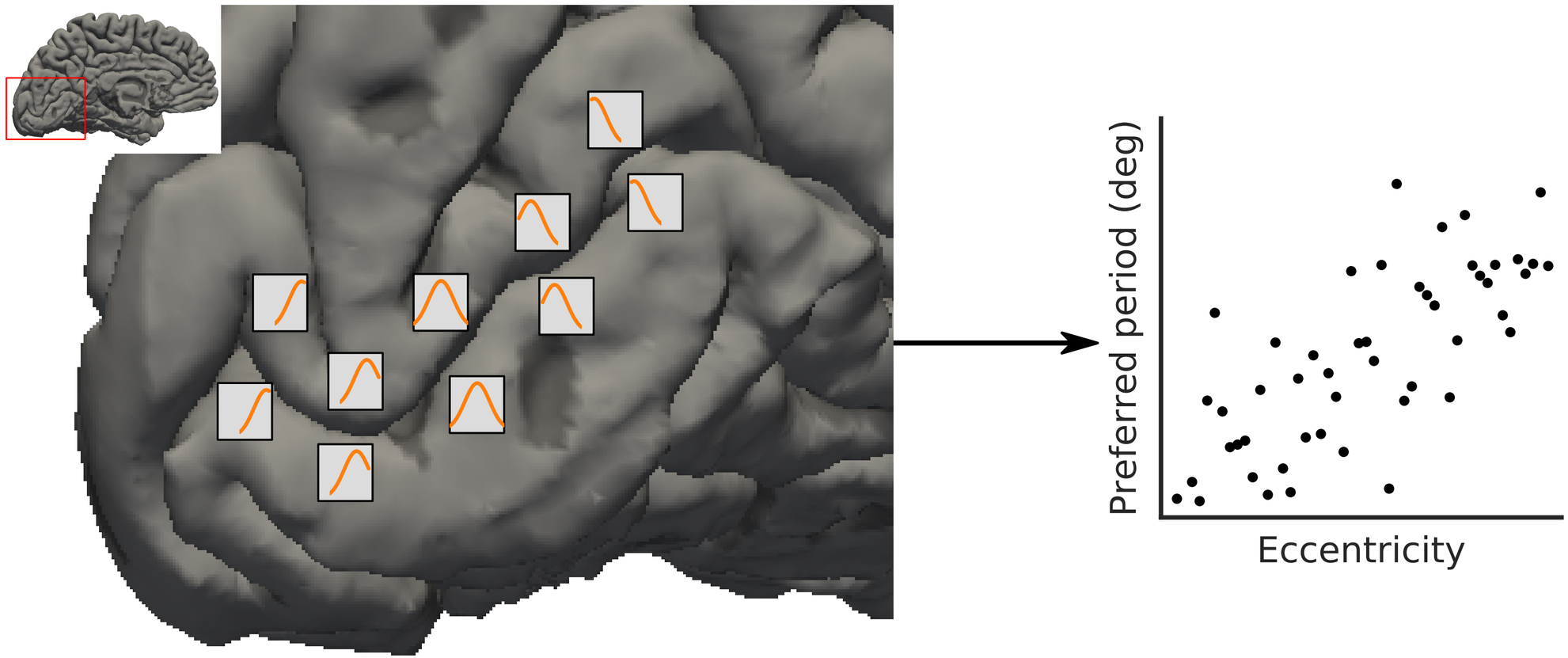
This holds across stimulus classes, though peak spatial frequency may differ


Response
(% BOLD signal change)
3.5
3.0
2.5
2.0
1.5
1.0
10^{-1}
10^{0}
10^{1}
Local spatial frequency (cpd)
Eccentricity band
2-3 deg
9-10 deg






Preferred period (deg)
Eccentricity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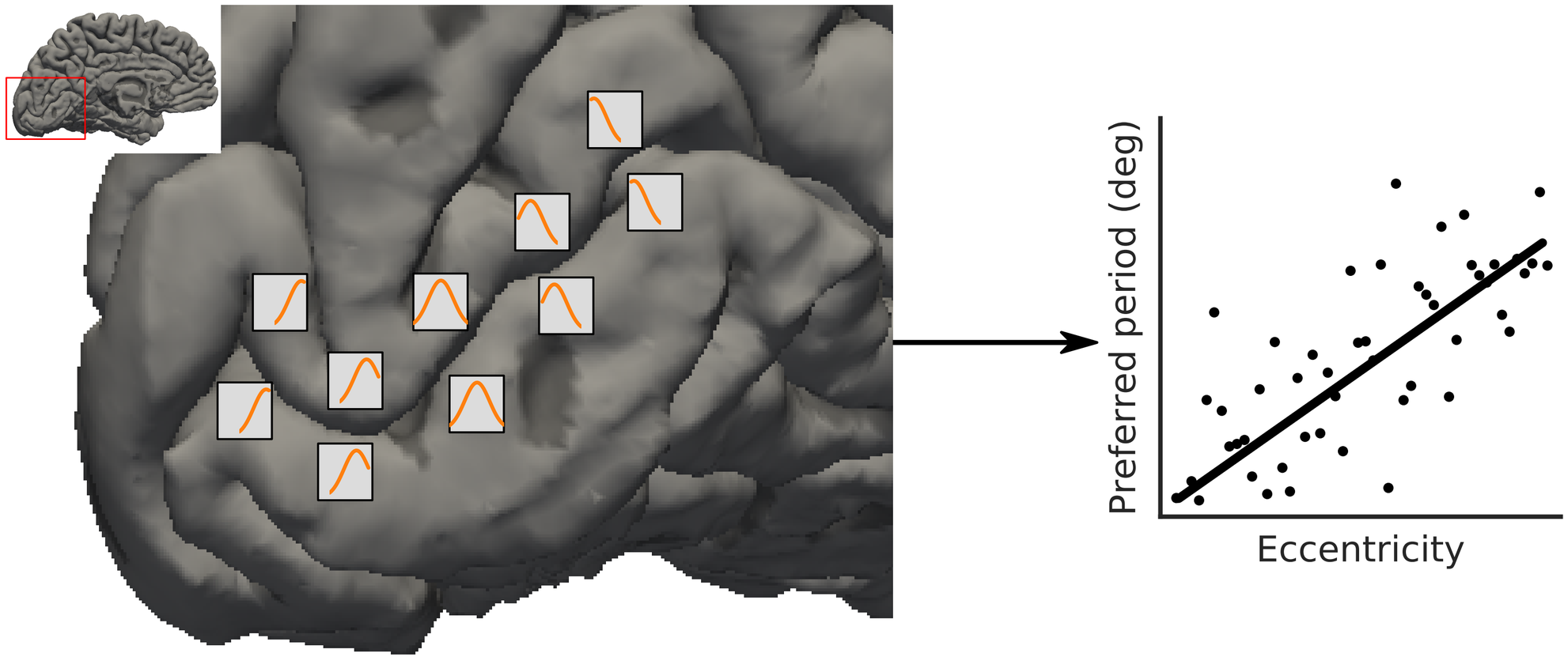
Preferred period (deg)
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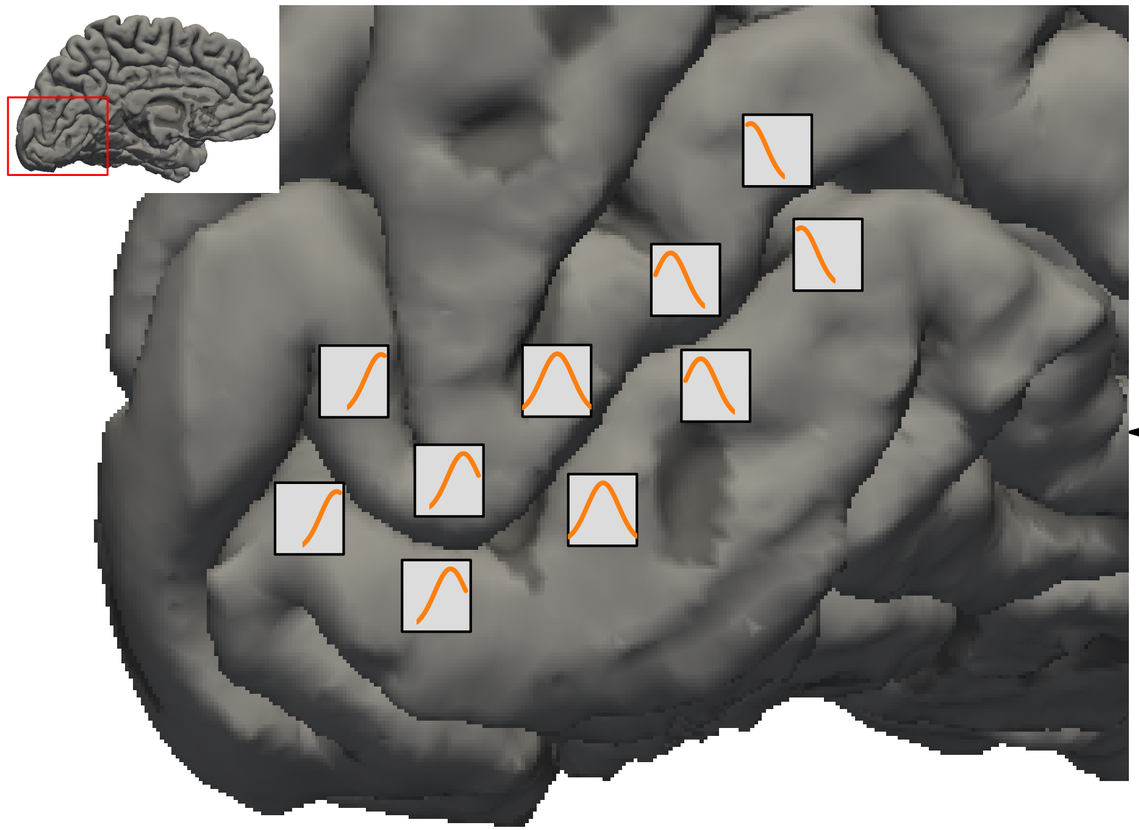
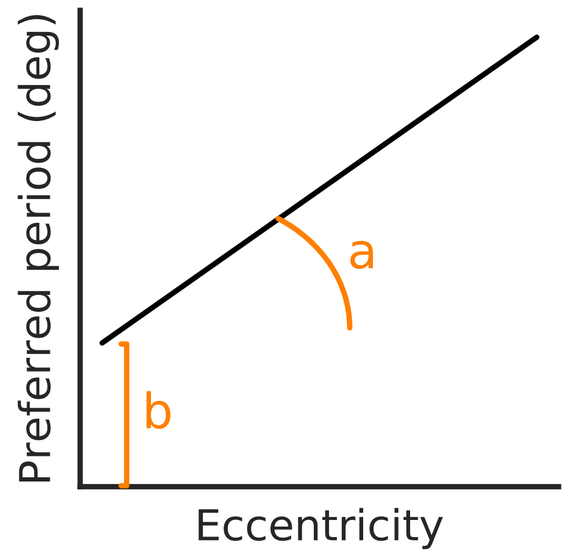


$$f(\omega, \theta, e, \phi, \dots)$$

Model parameters

- Affine relationship between eccentricity and preferred period (2 parameters)



Model parameters

- Affine relationship between eccentricity and preferred period (2 parameters)
- Modulation of preferred period by orientation (4 parameters)

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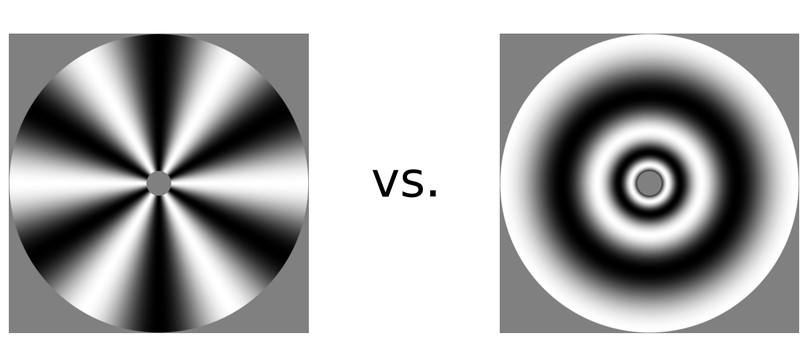
  - Annuli vs. pinwheels (1 parameter)



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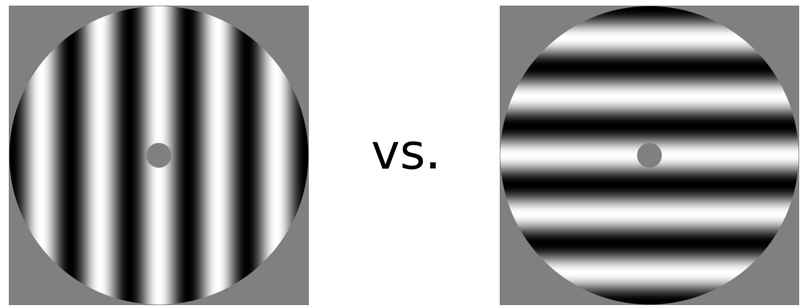

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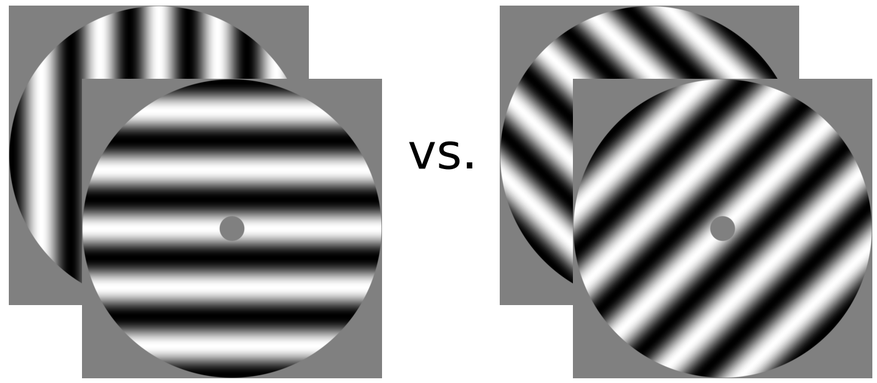

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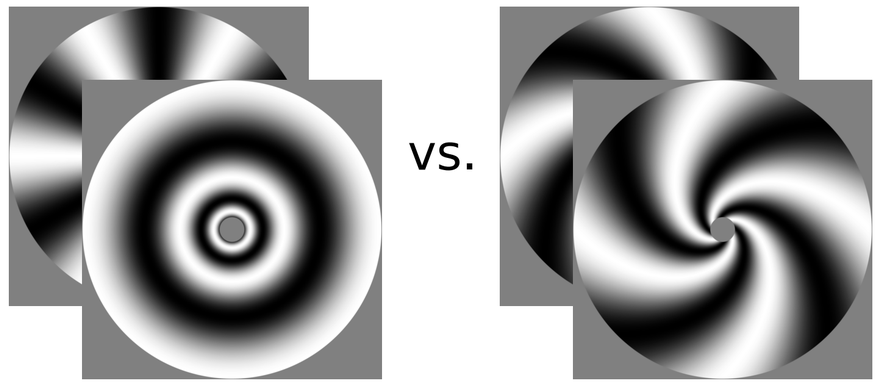

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absolute

relative

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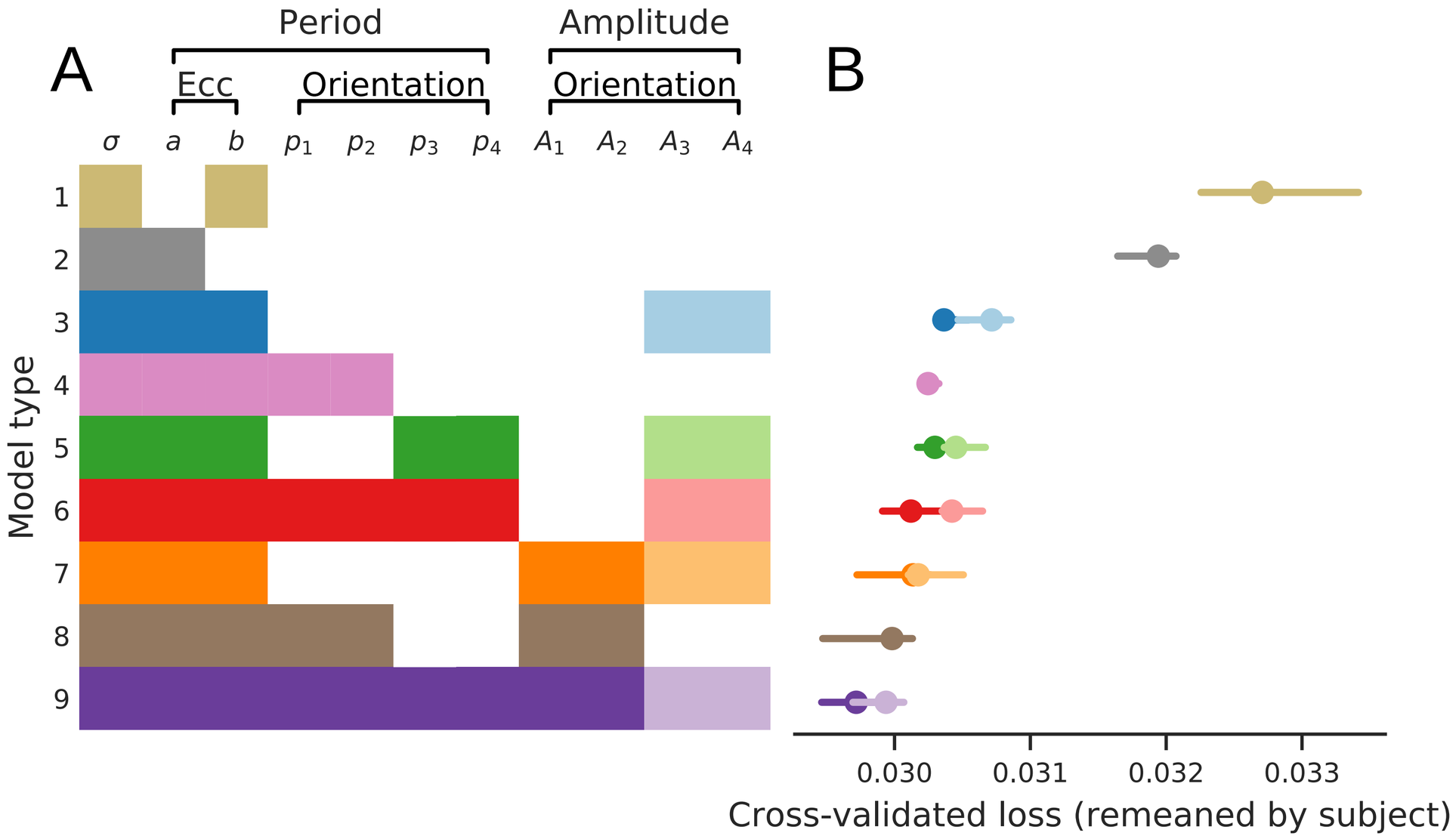
Largest effect is eccentricity dependence, others are modest



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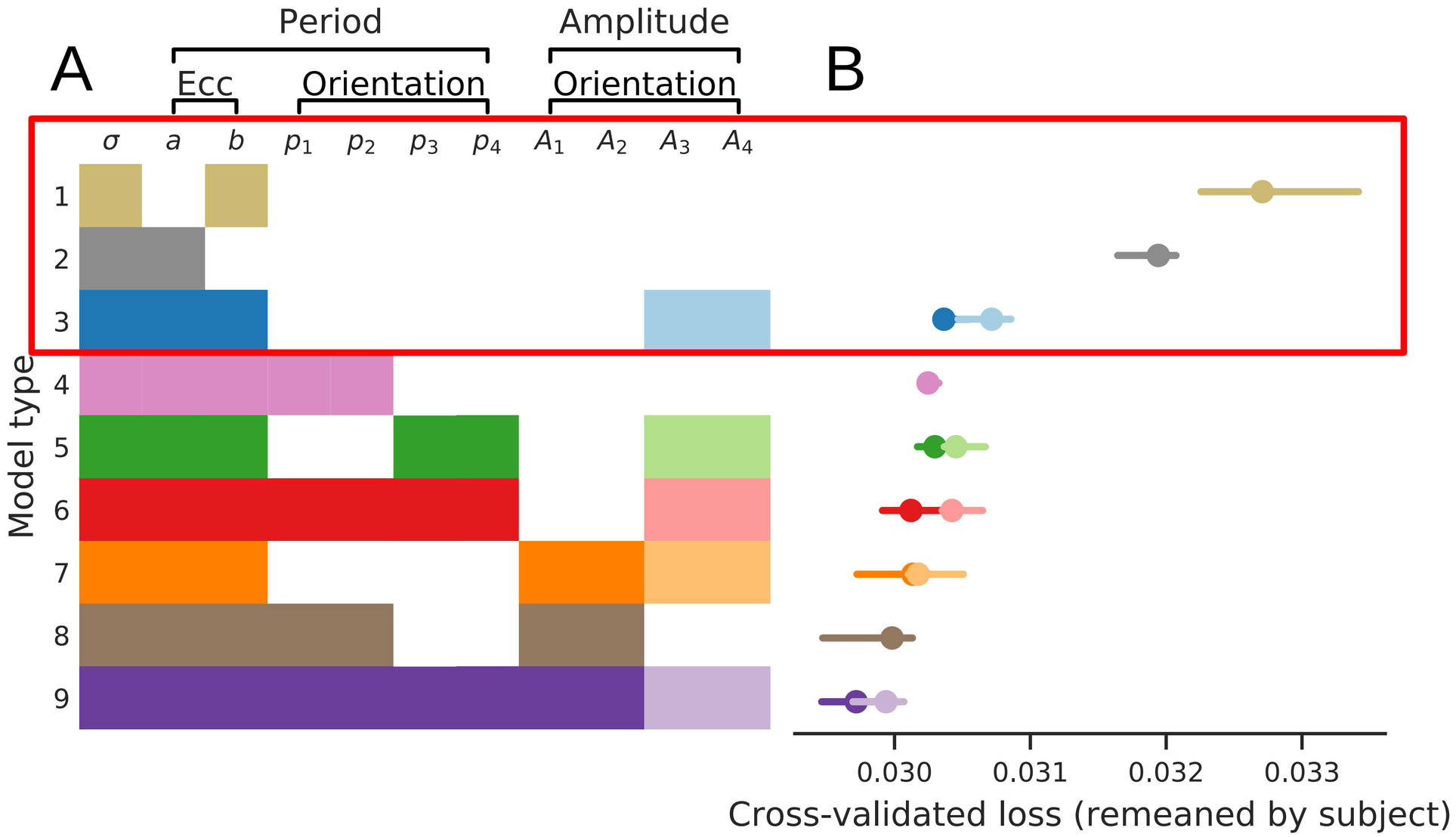

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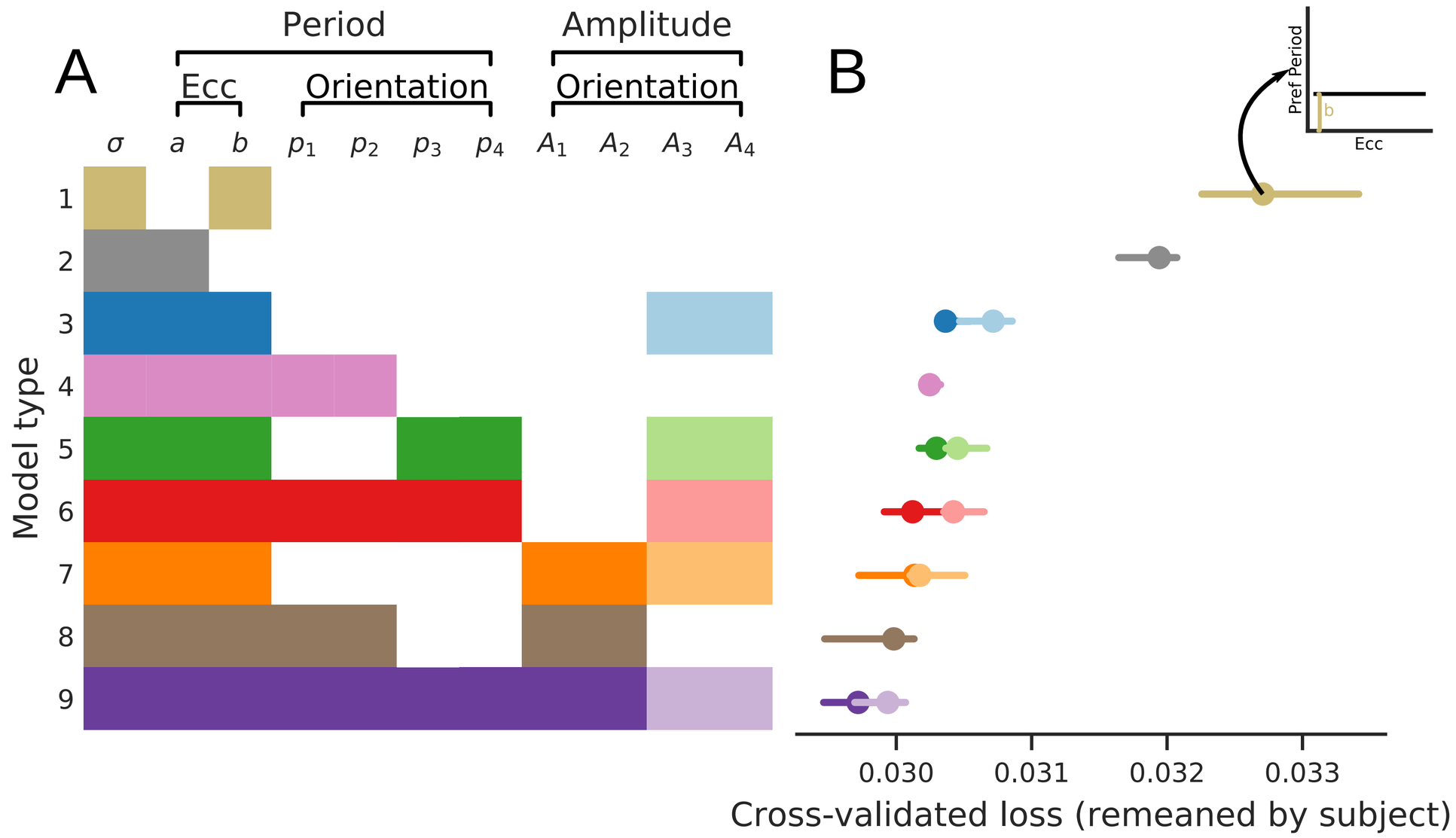

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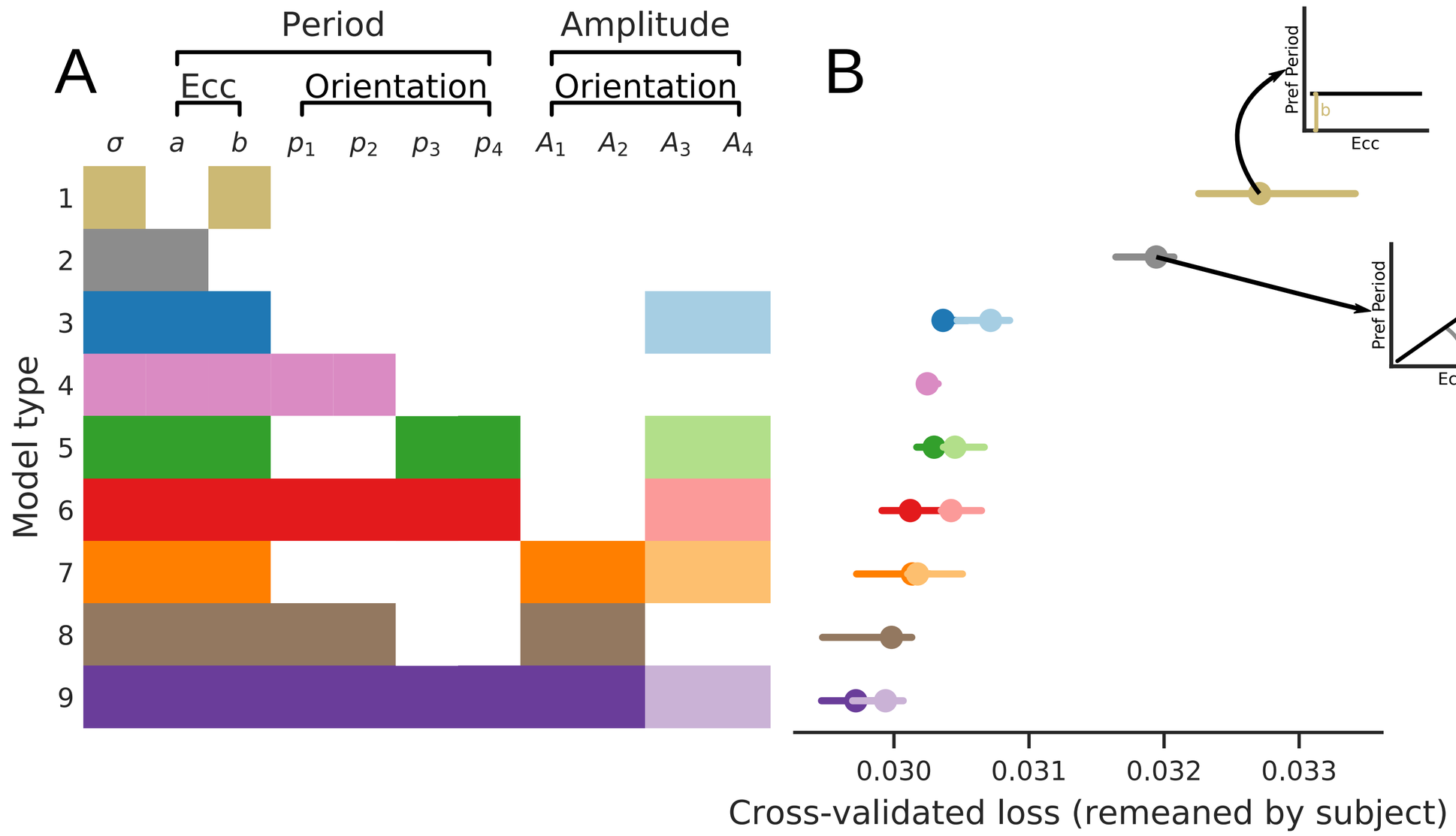

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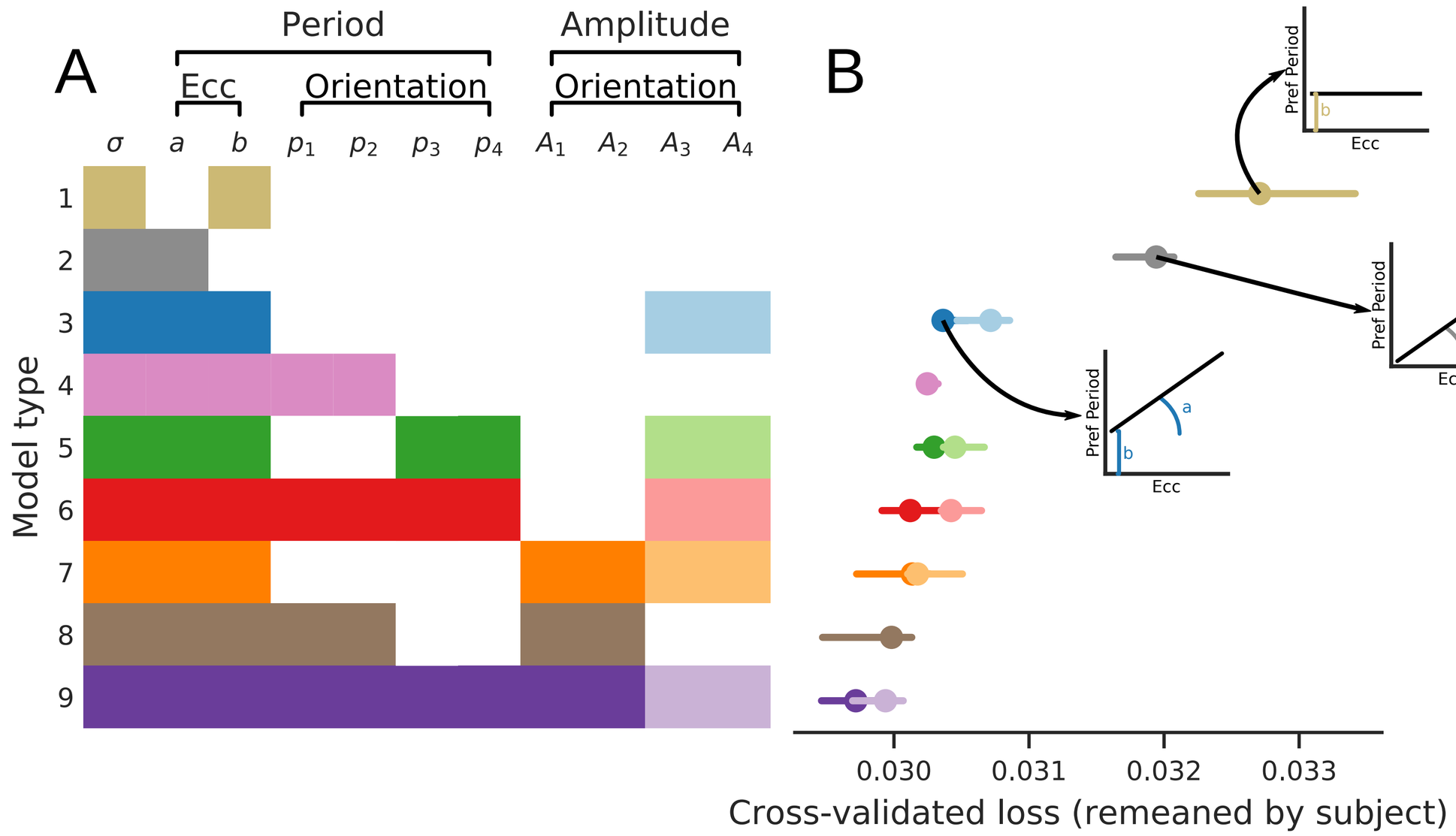
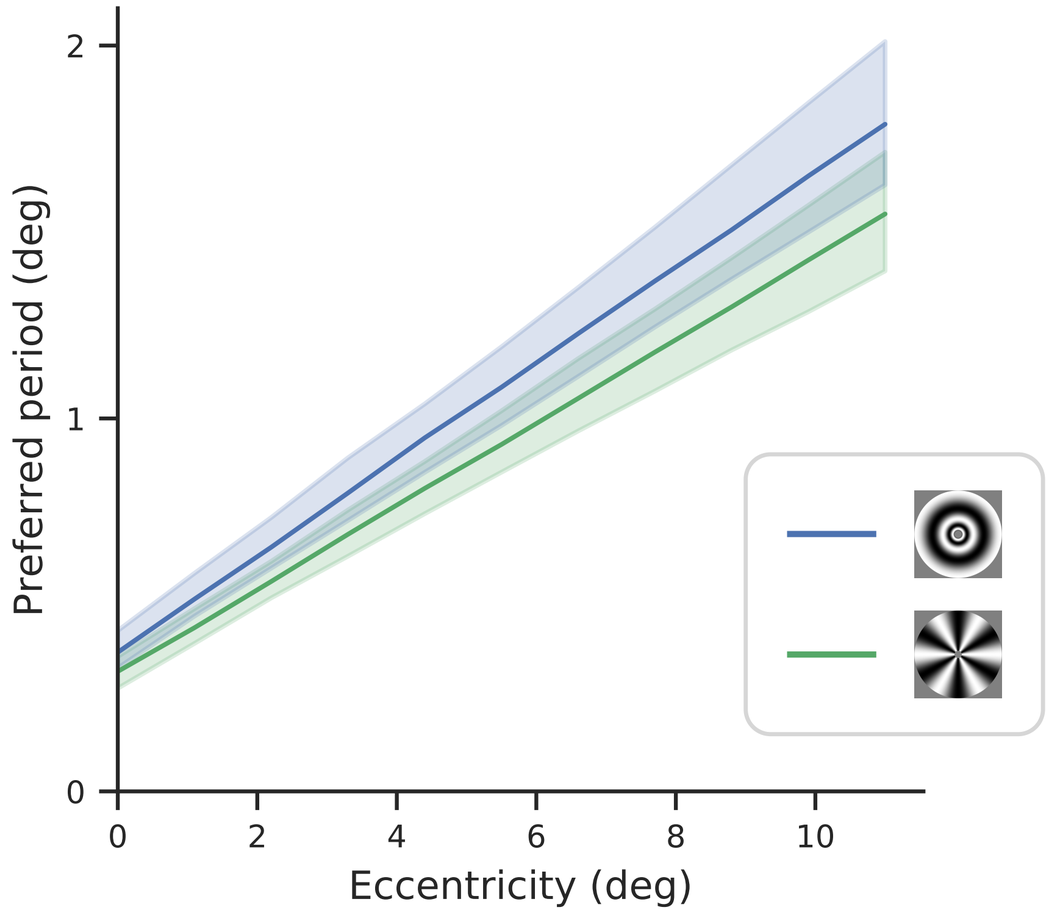
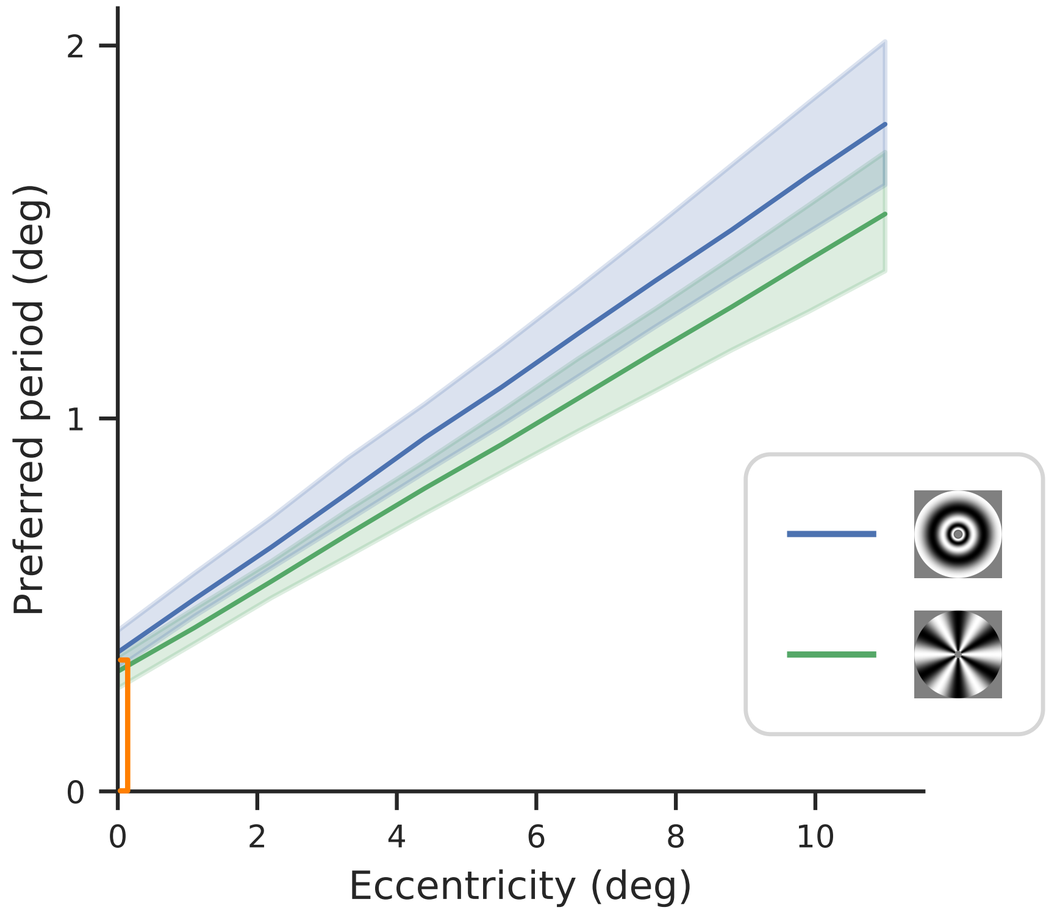


Preferred period is an affine function of eccentricity



Size of offset equivalent to 3 degrees eccentricity



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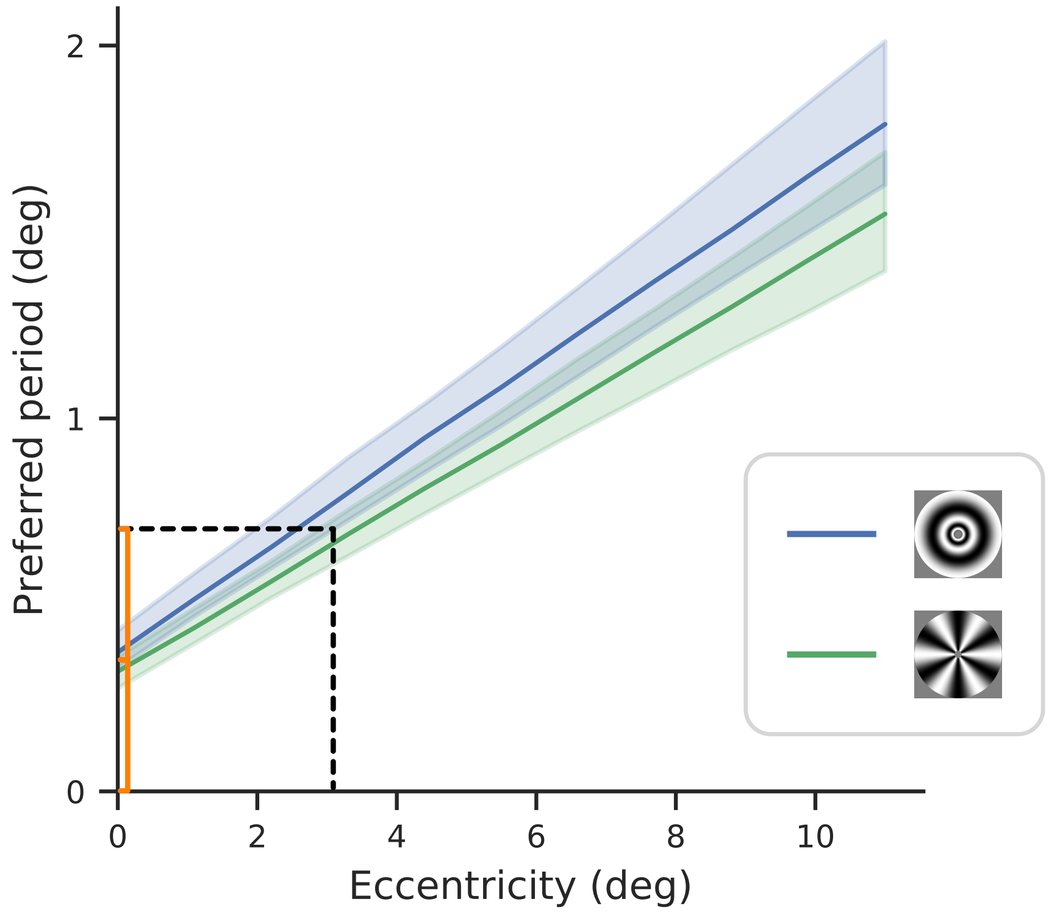
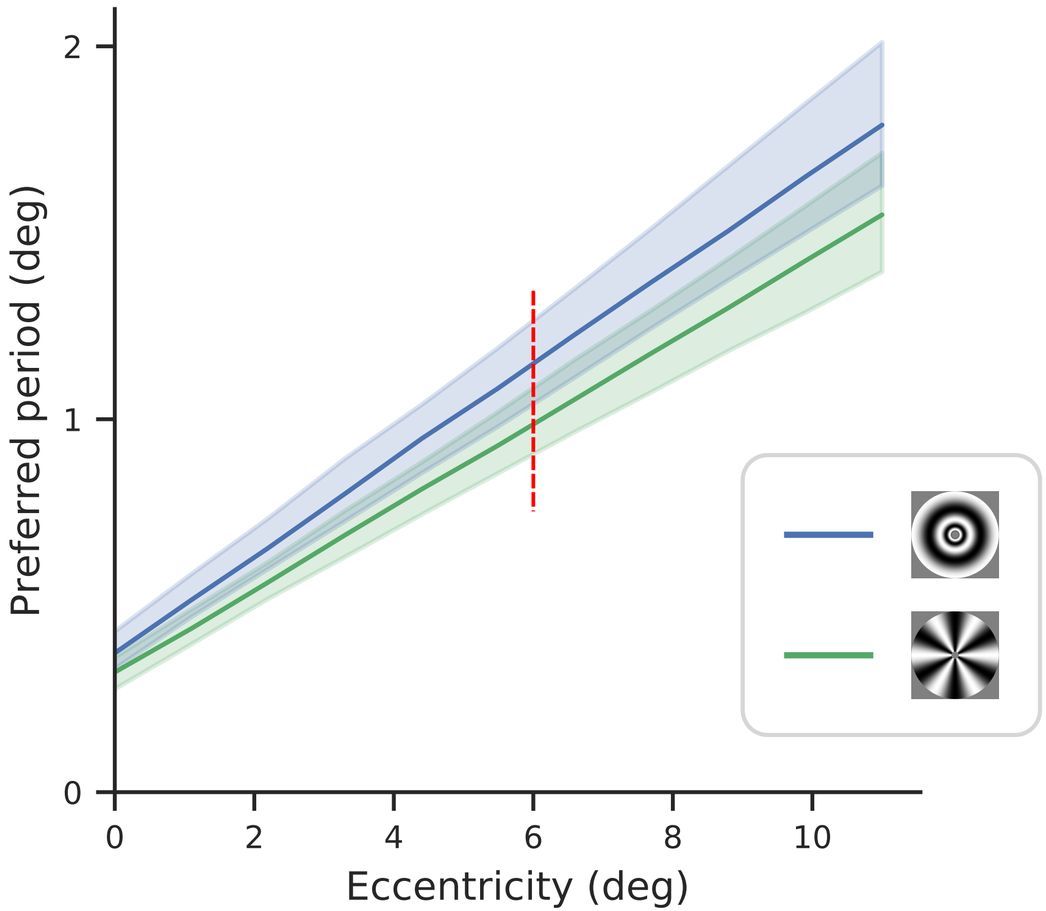
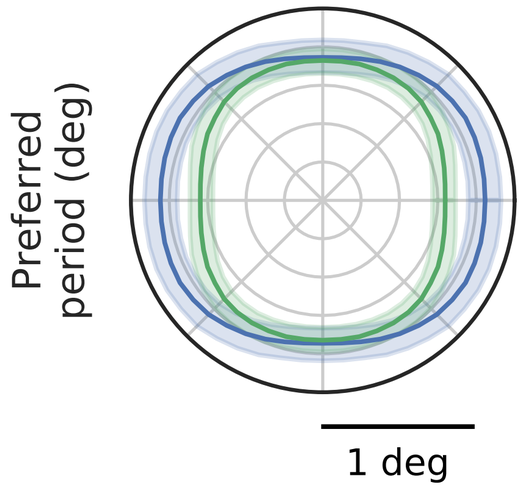


Effect of orientation largest at horizontal meridian, disappears at vertical


Preferred period (deg)
2
1
0
0
2
4
6
8
10
Eccentricity (deg)


Preferred period (deg)
1 deg

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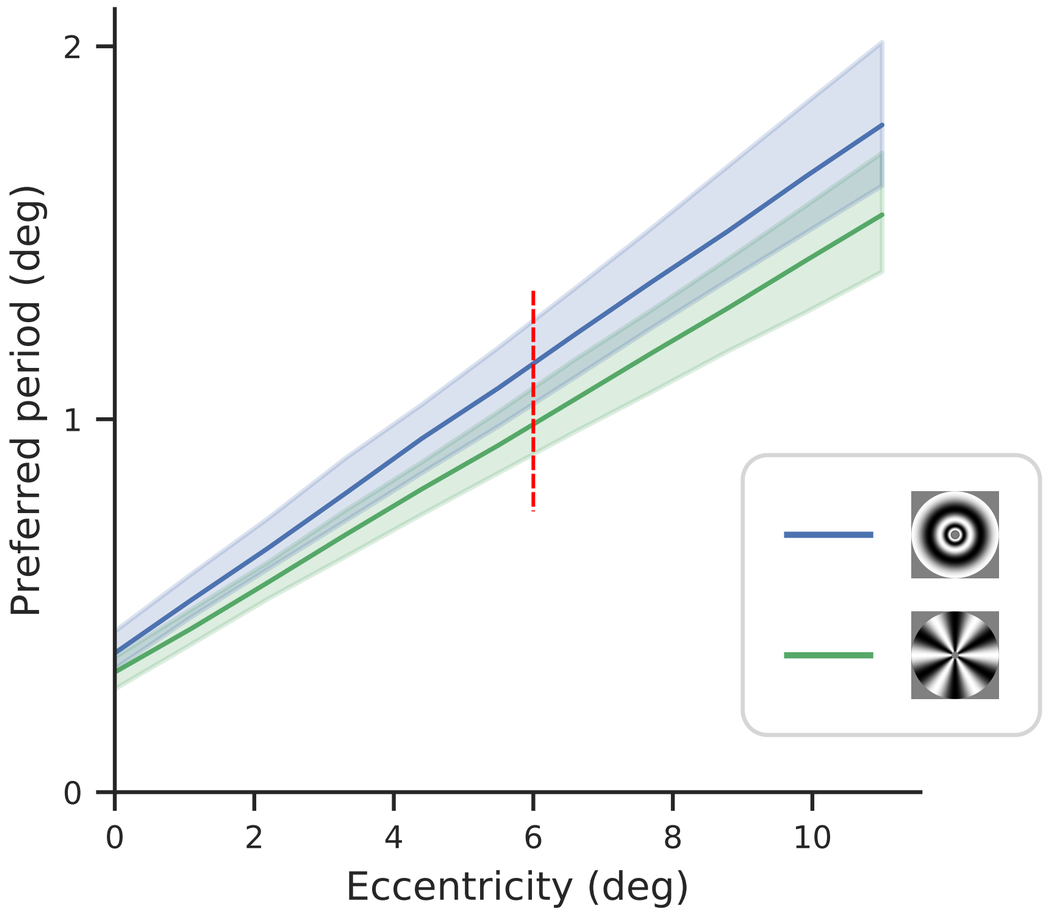
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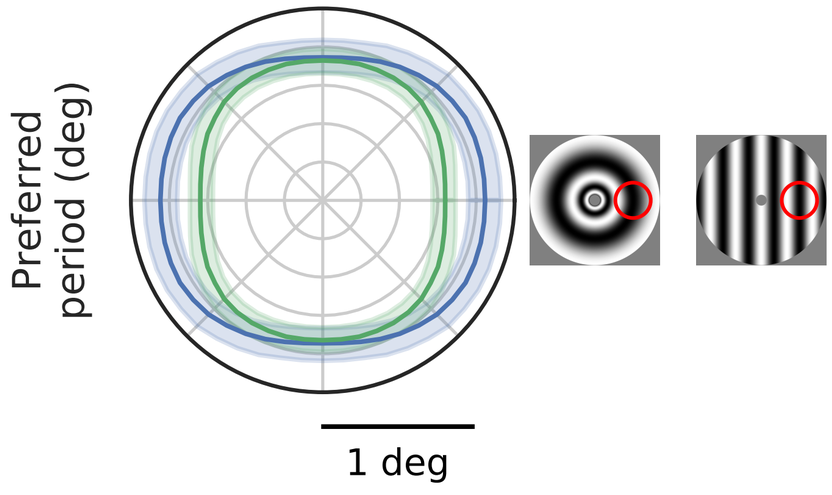
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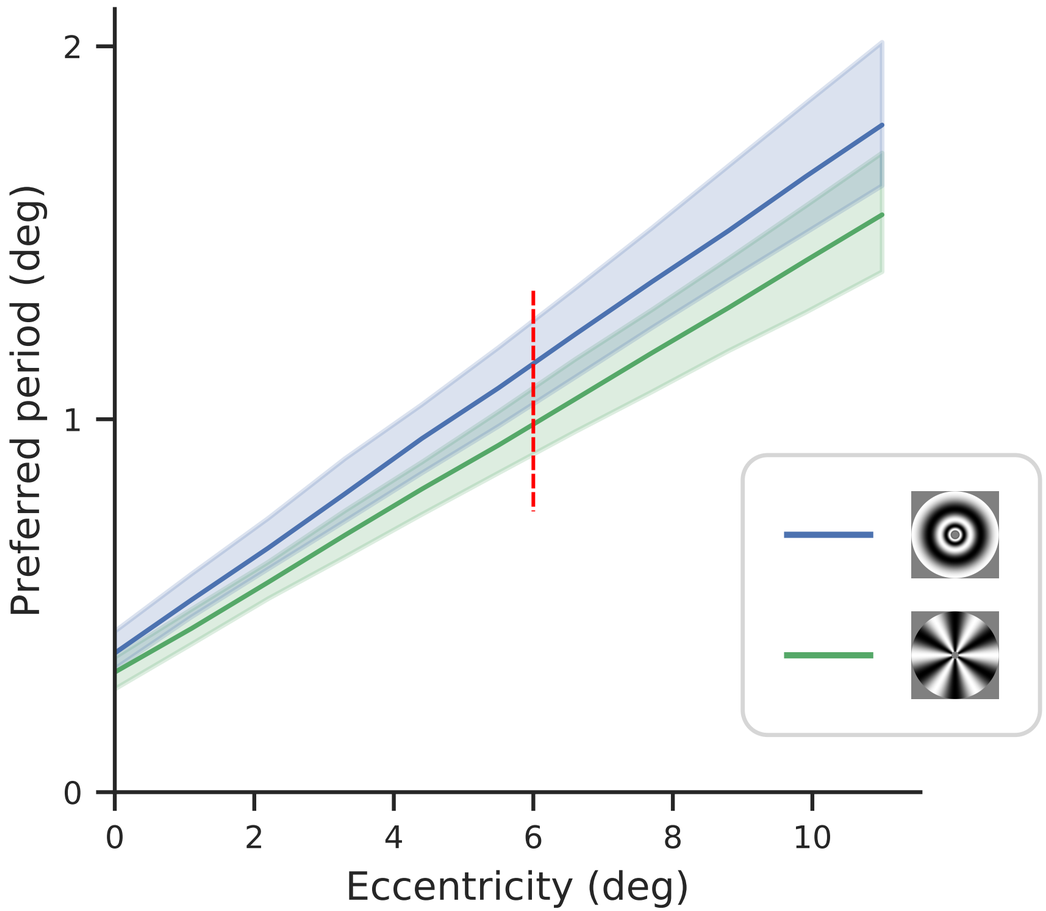
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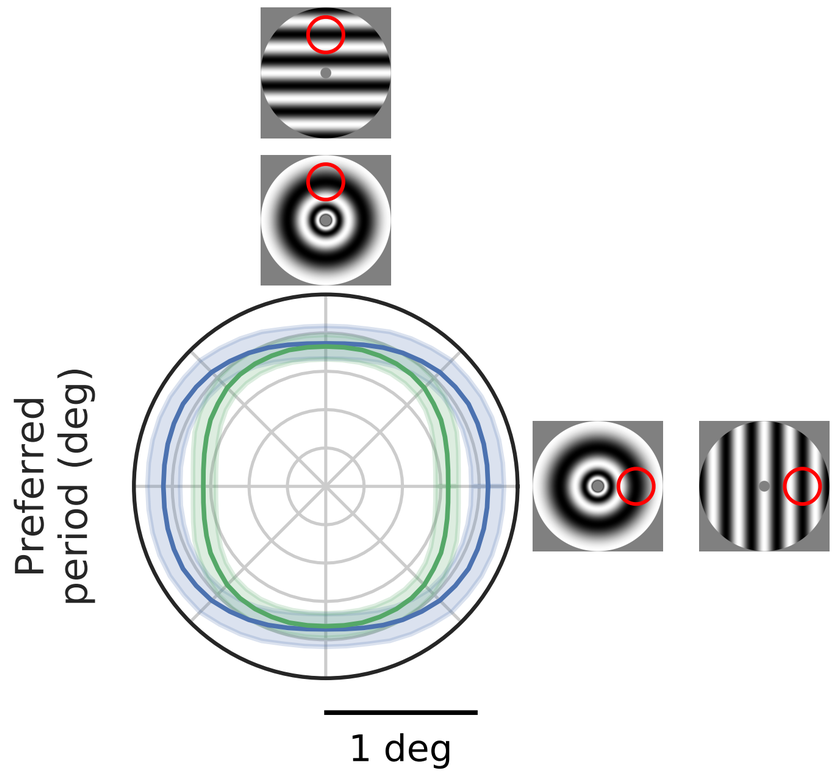
Preferred
period (deg)
1 deg

Intermediate conclusions

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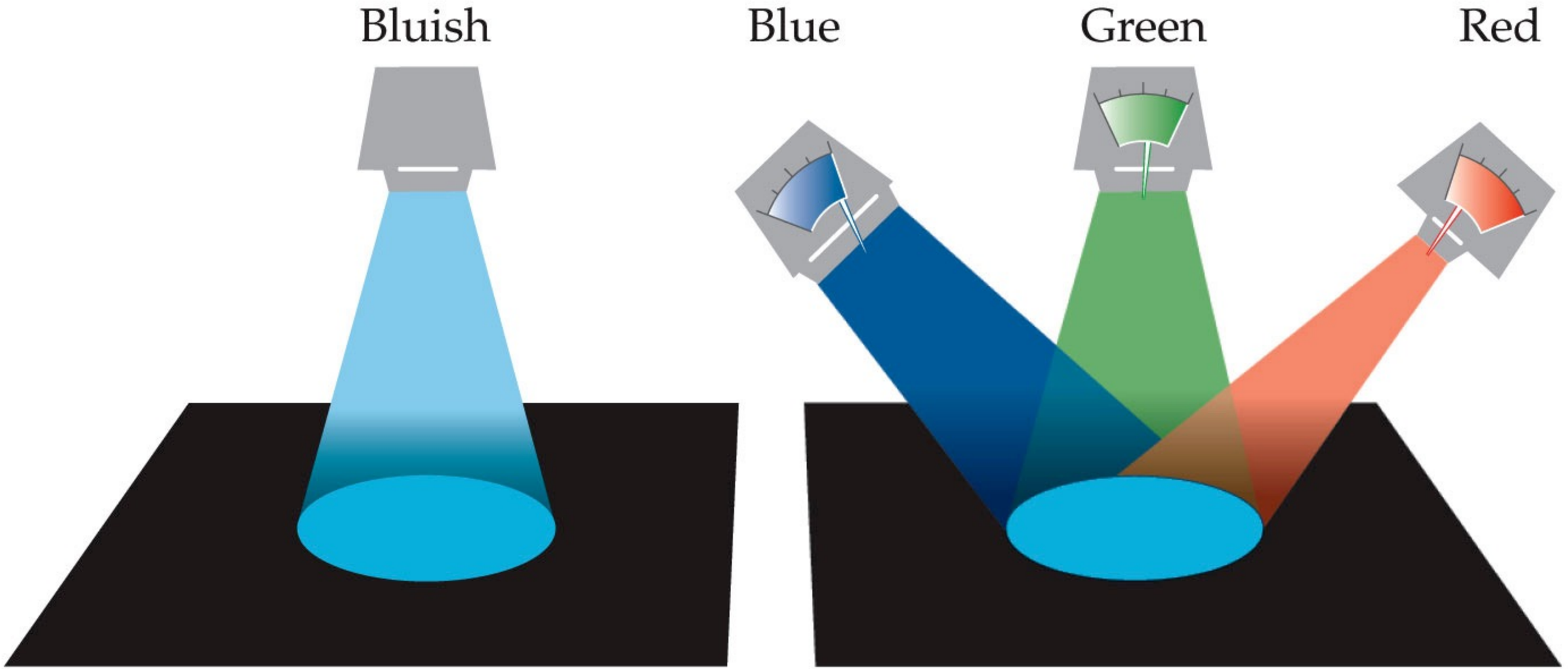
- Serves as a step towards a generalized model of whole map

What information does the early visual system *discard?*

Perceptual metamers



Perceptual ability is not uniform across the visual field

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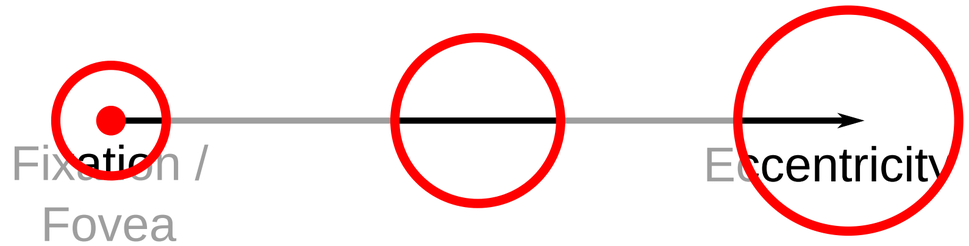

Project overview

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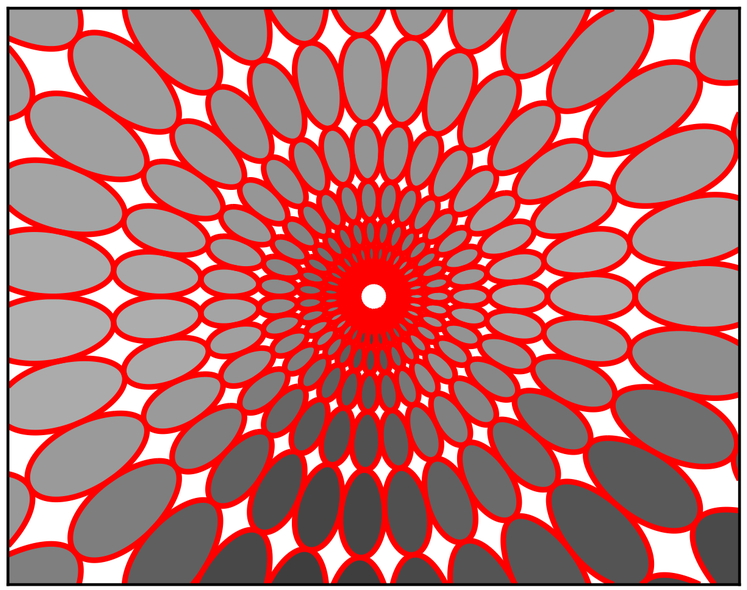
Local average luminance model

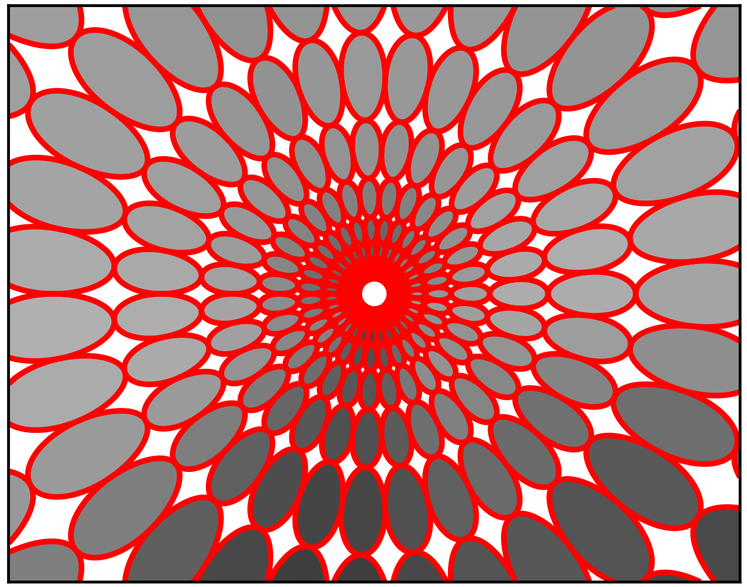
Image

Model representation

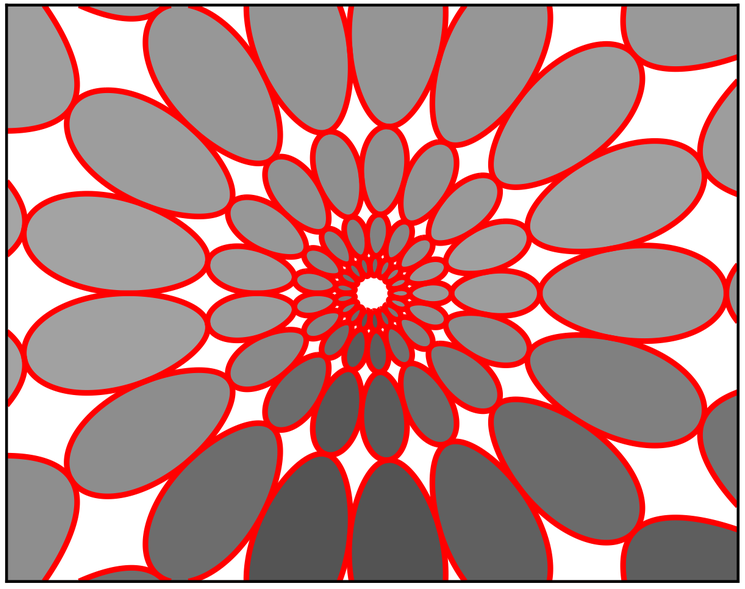


These models have a single parameter: scaling

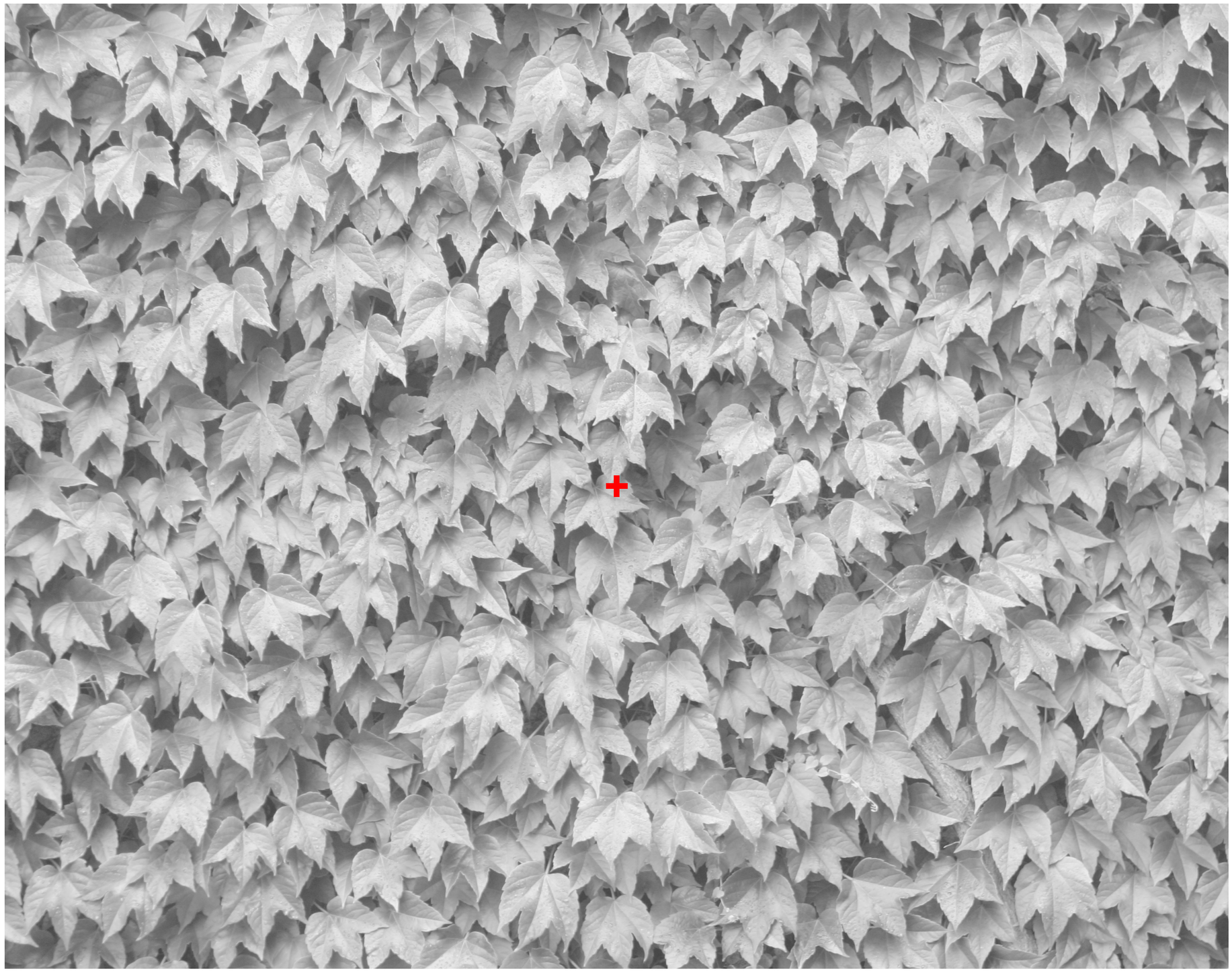
Low scaling

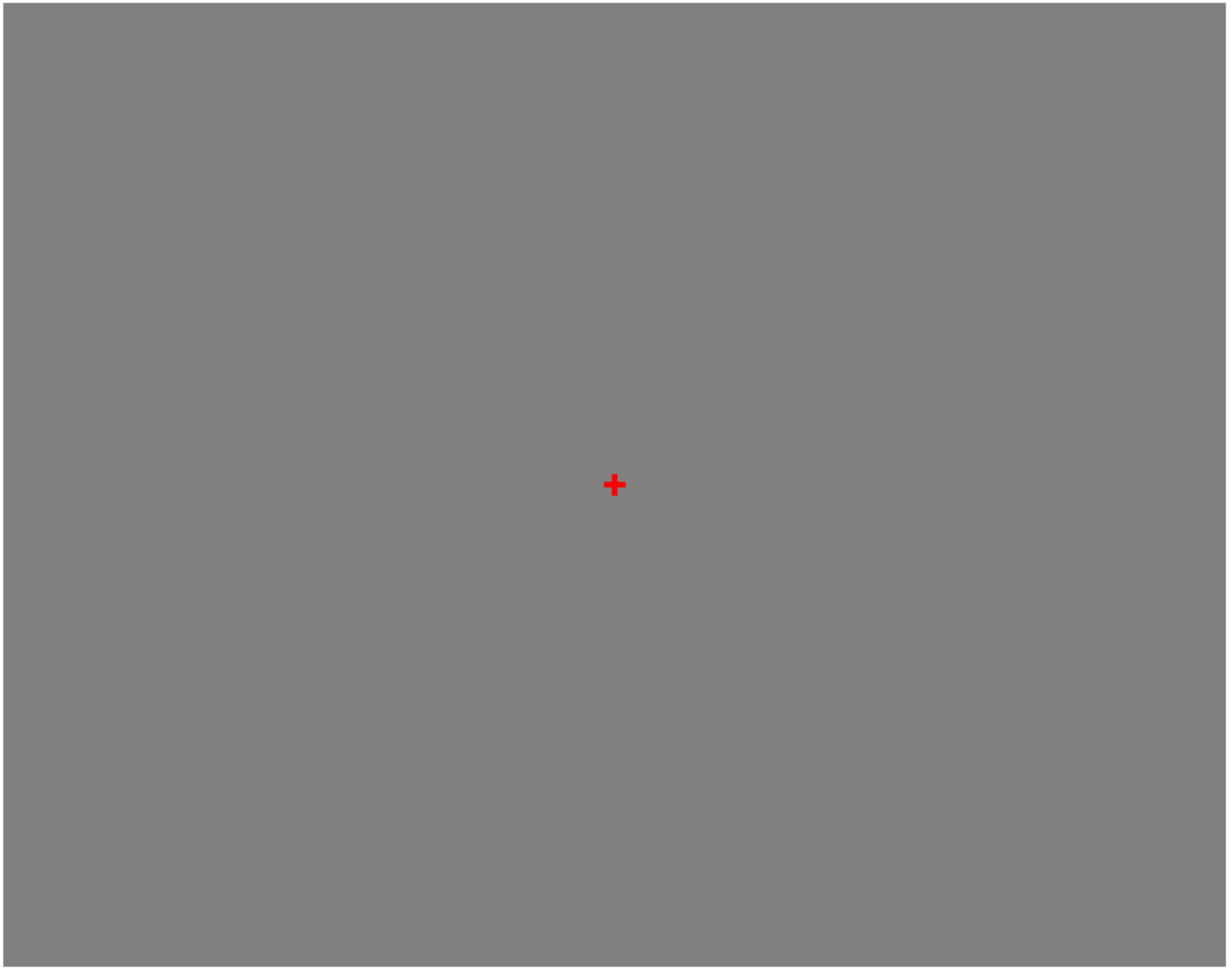


High scaling



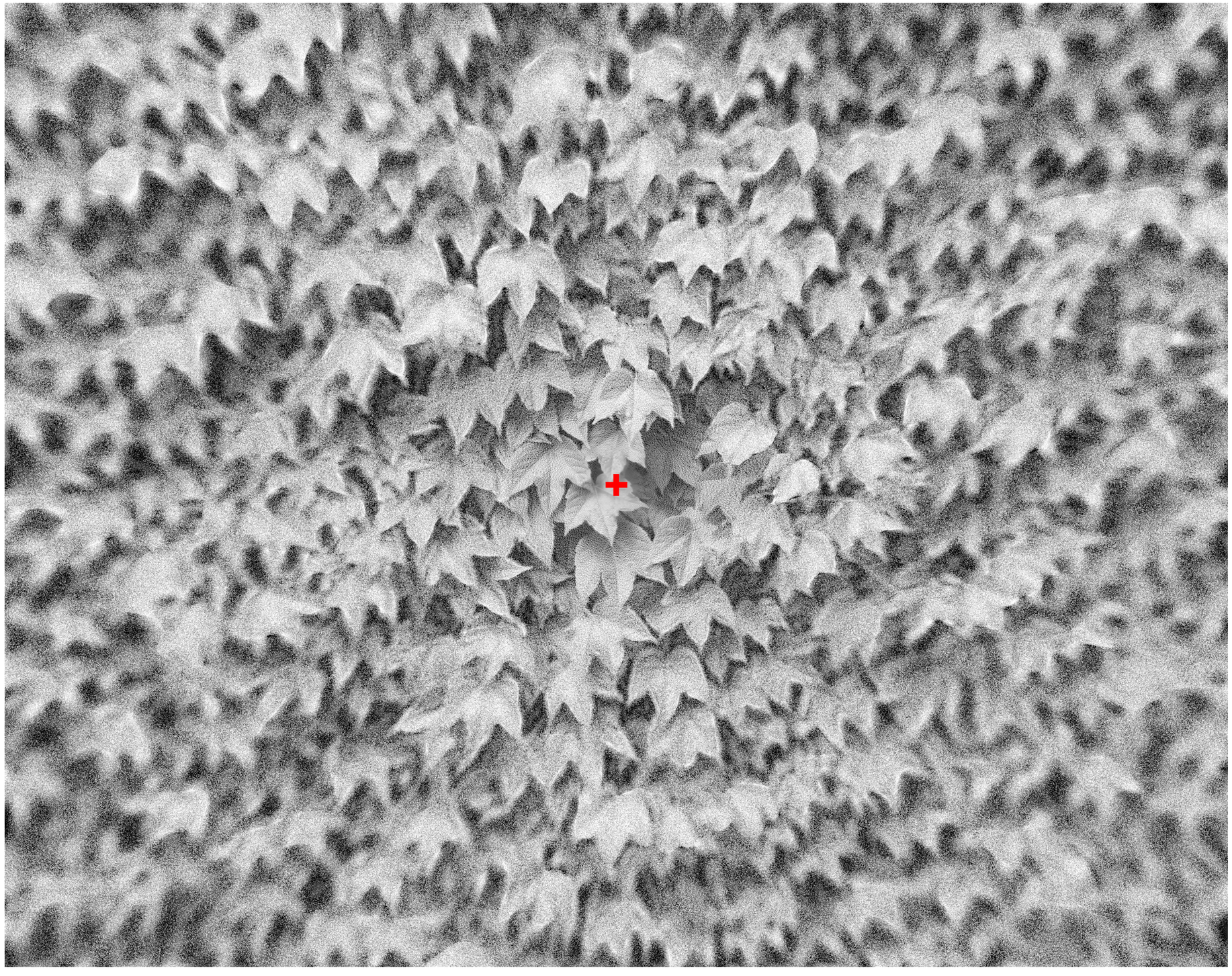
Target Image





Metamer for Lum(0.058)

Not human metamer



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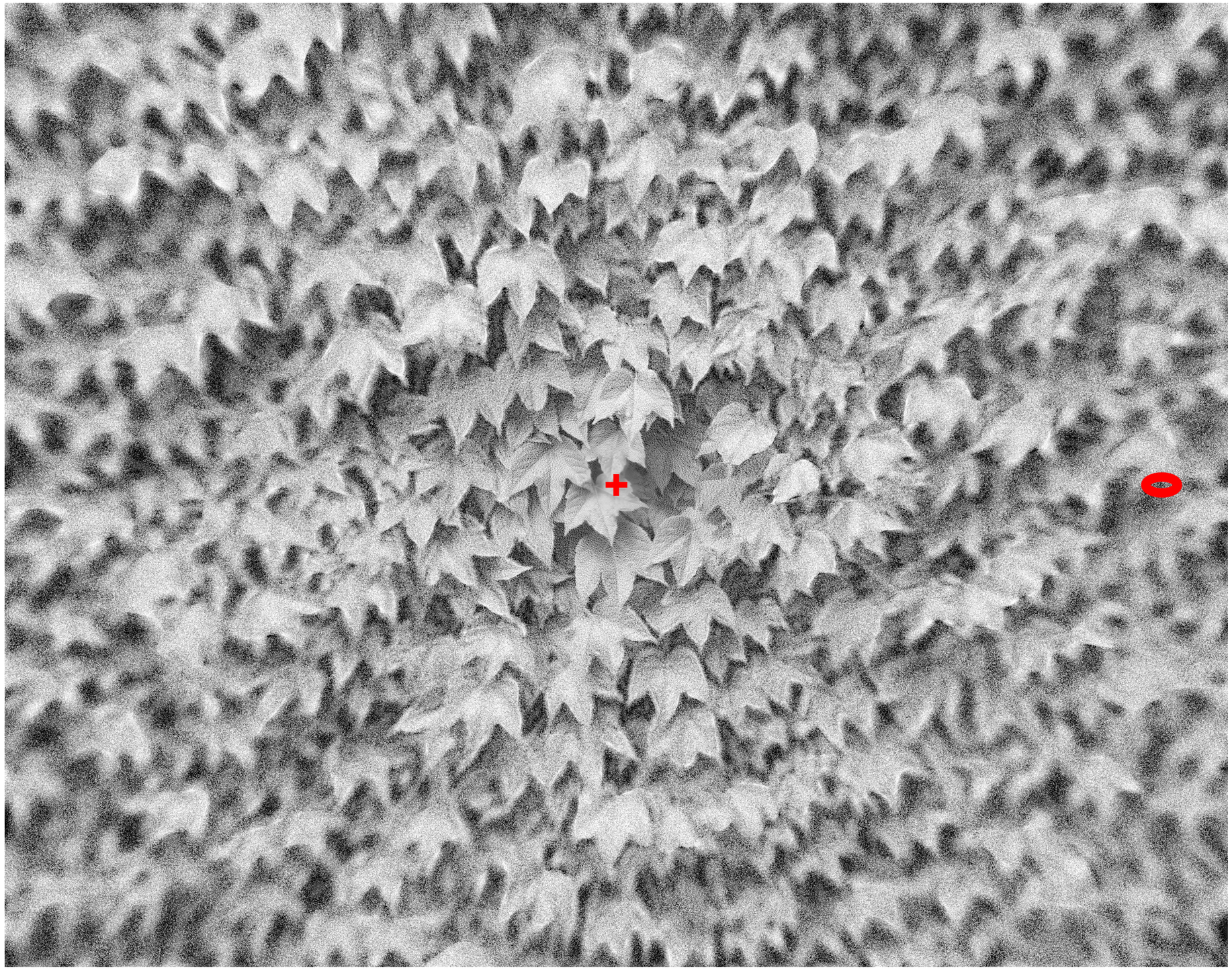

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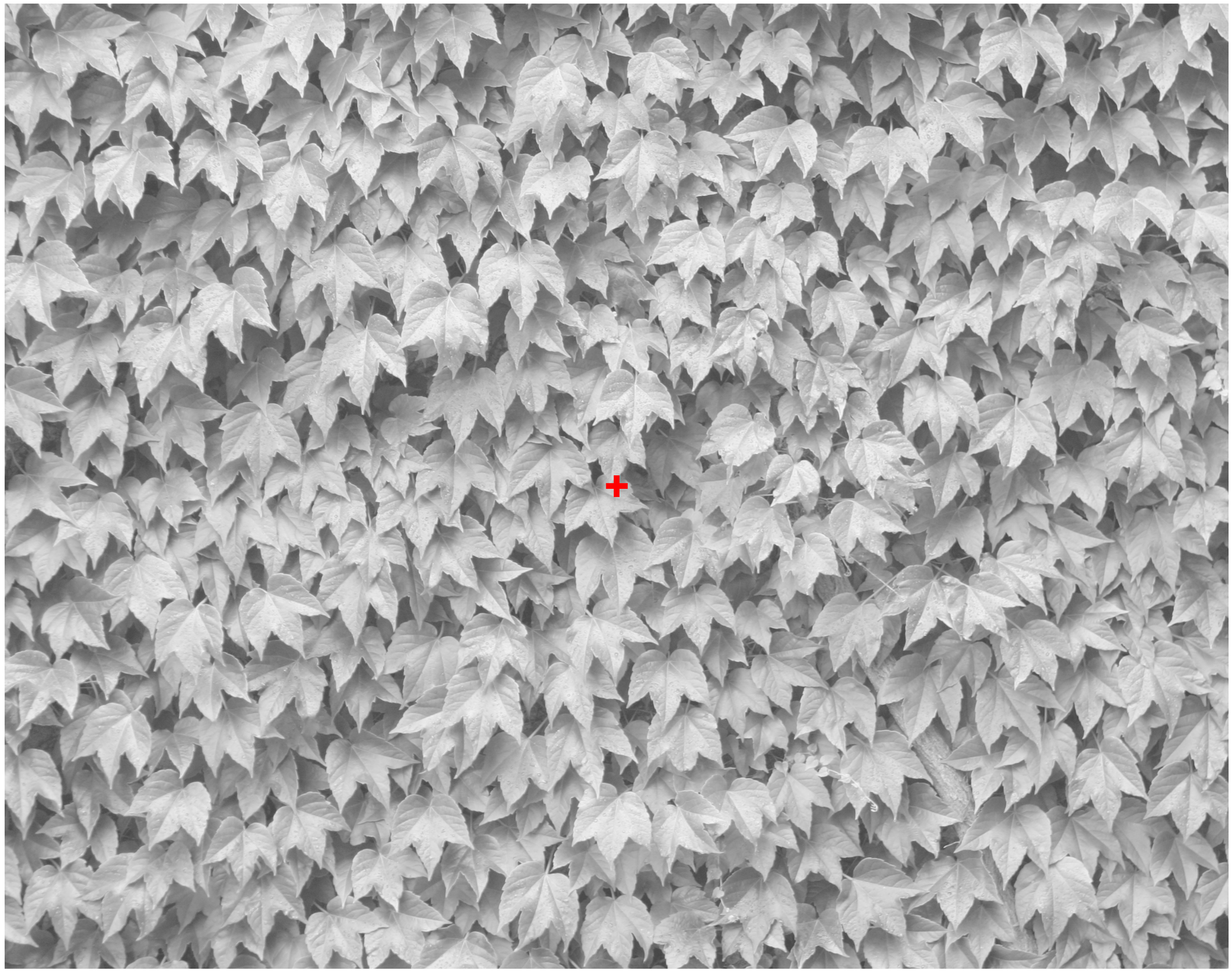
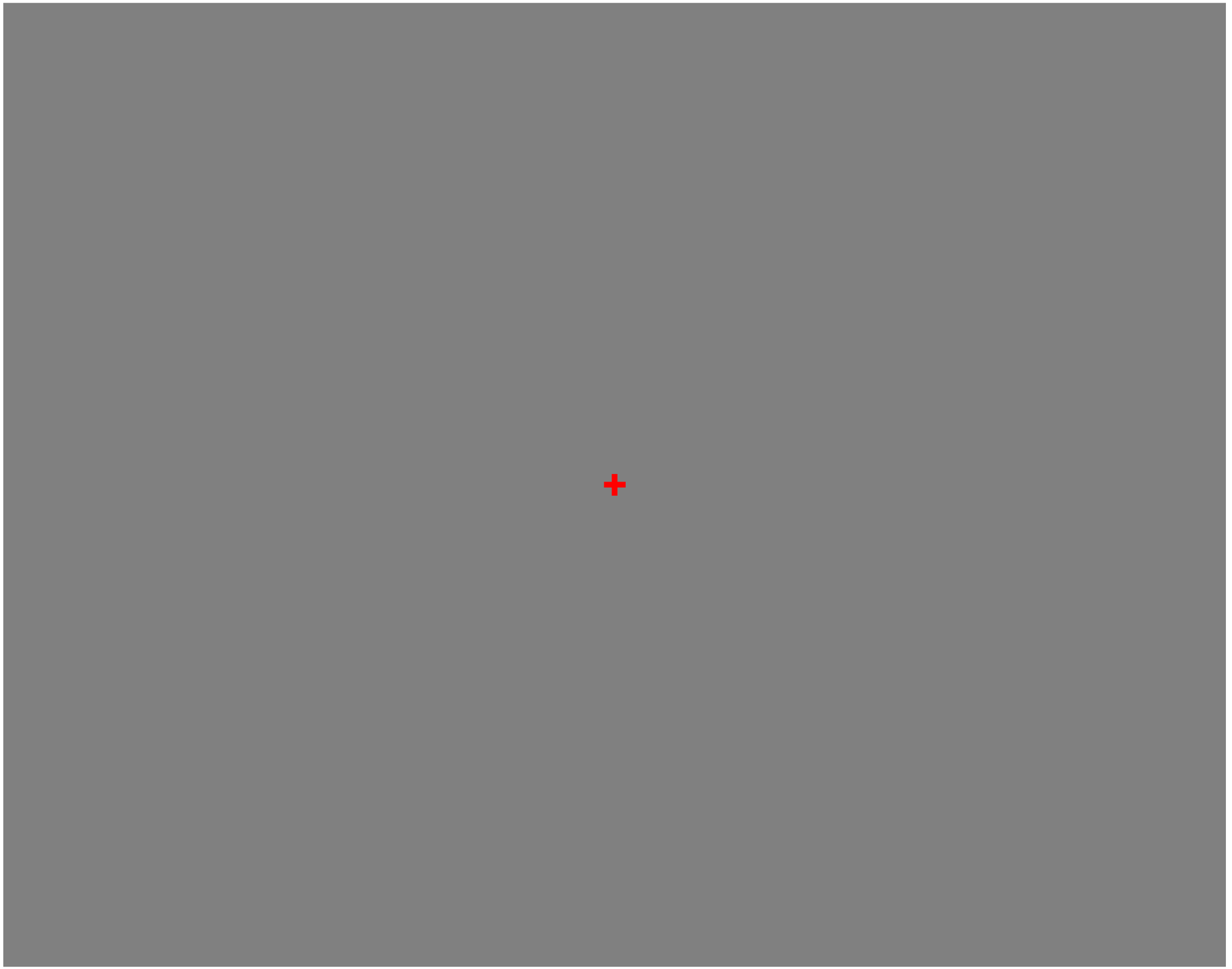
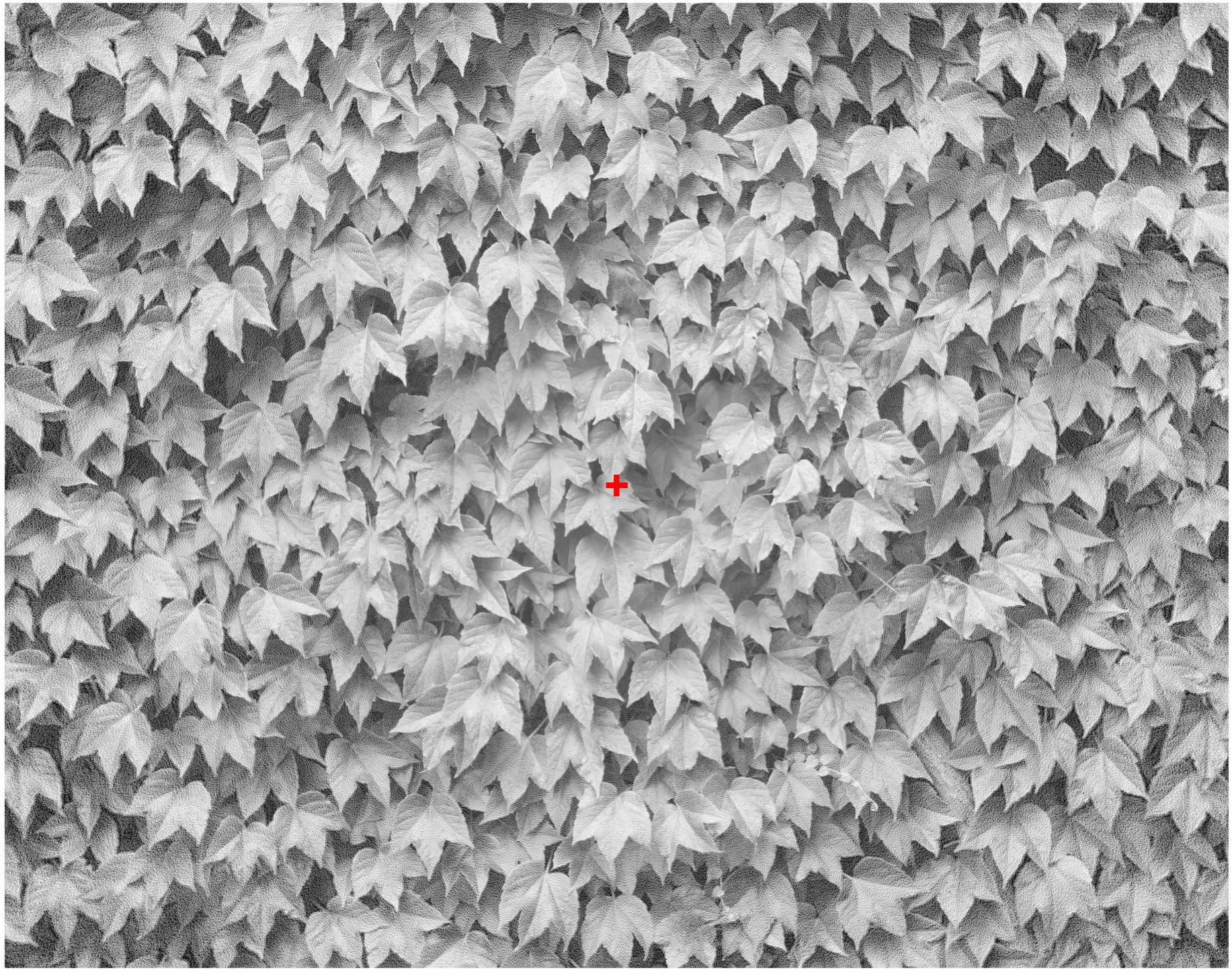




Metamer for Lum(.01)

Human metamer?



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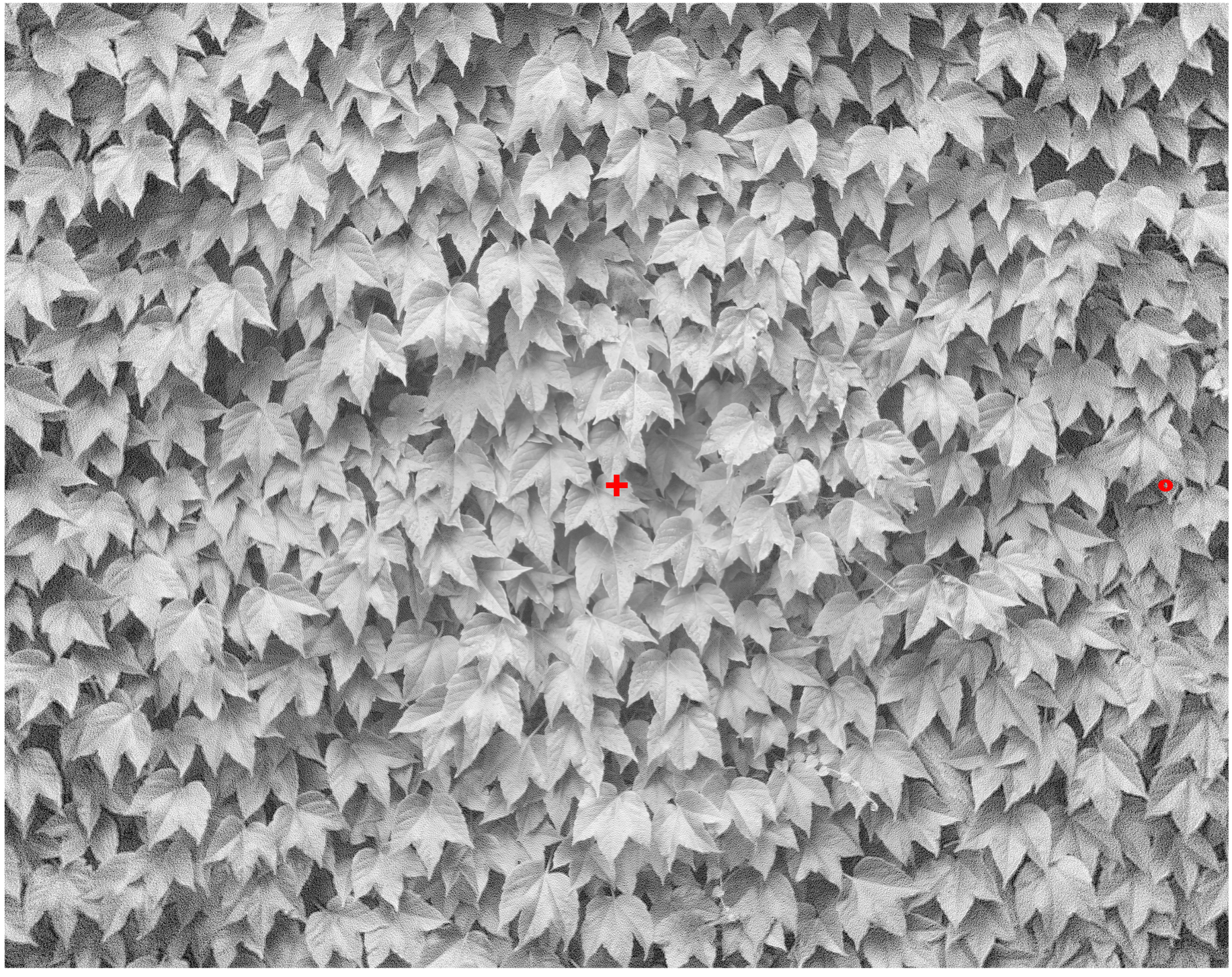

Metamer for Lum(.01)

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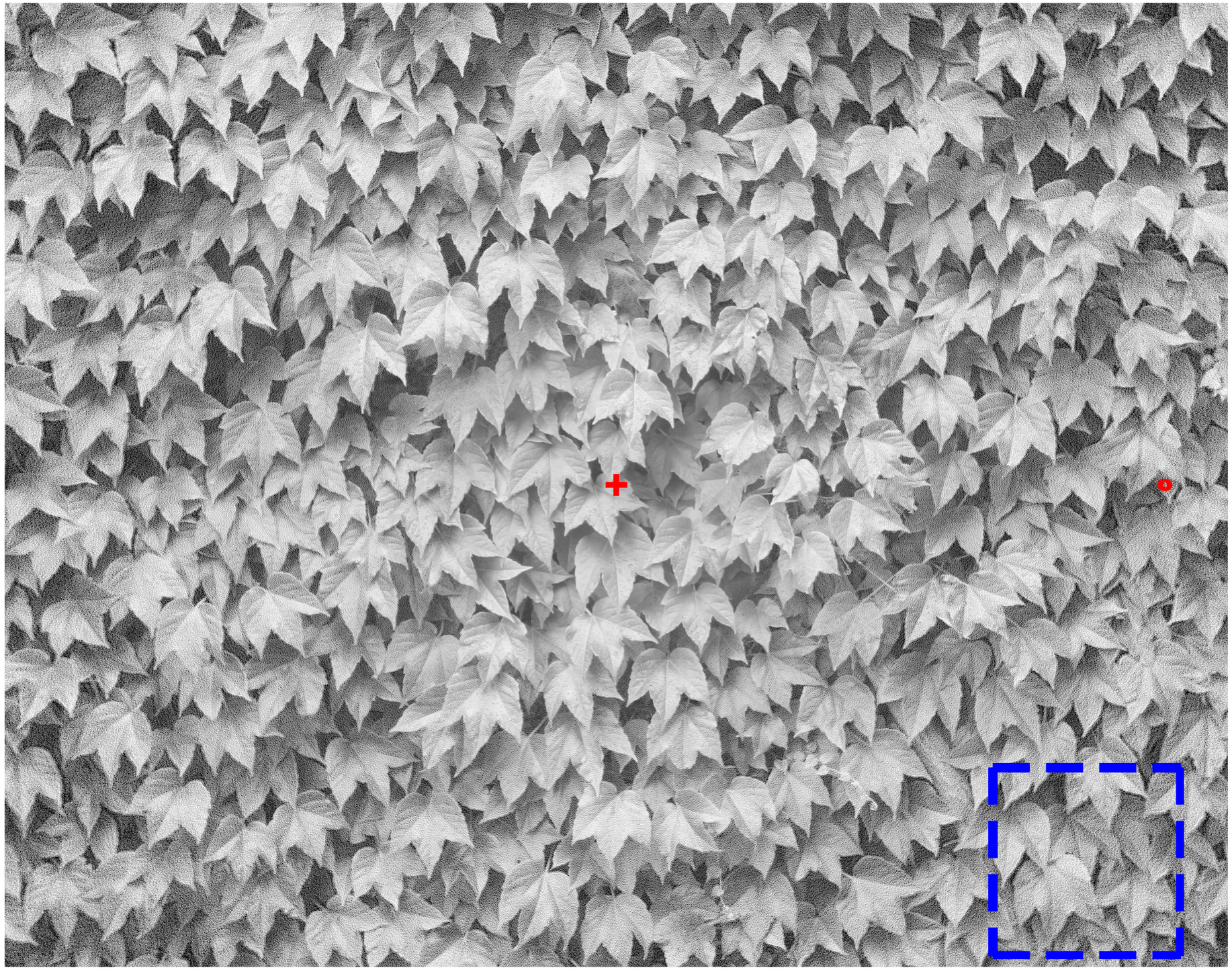

Metamer for Lum(.01)

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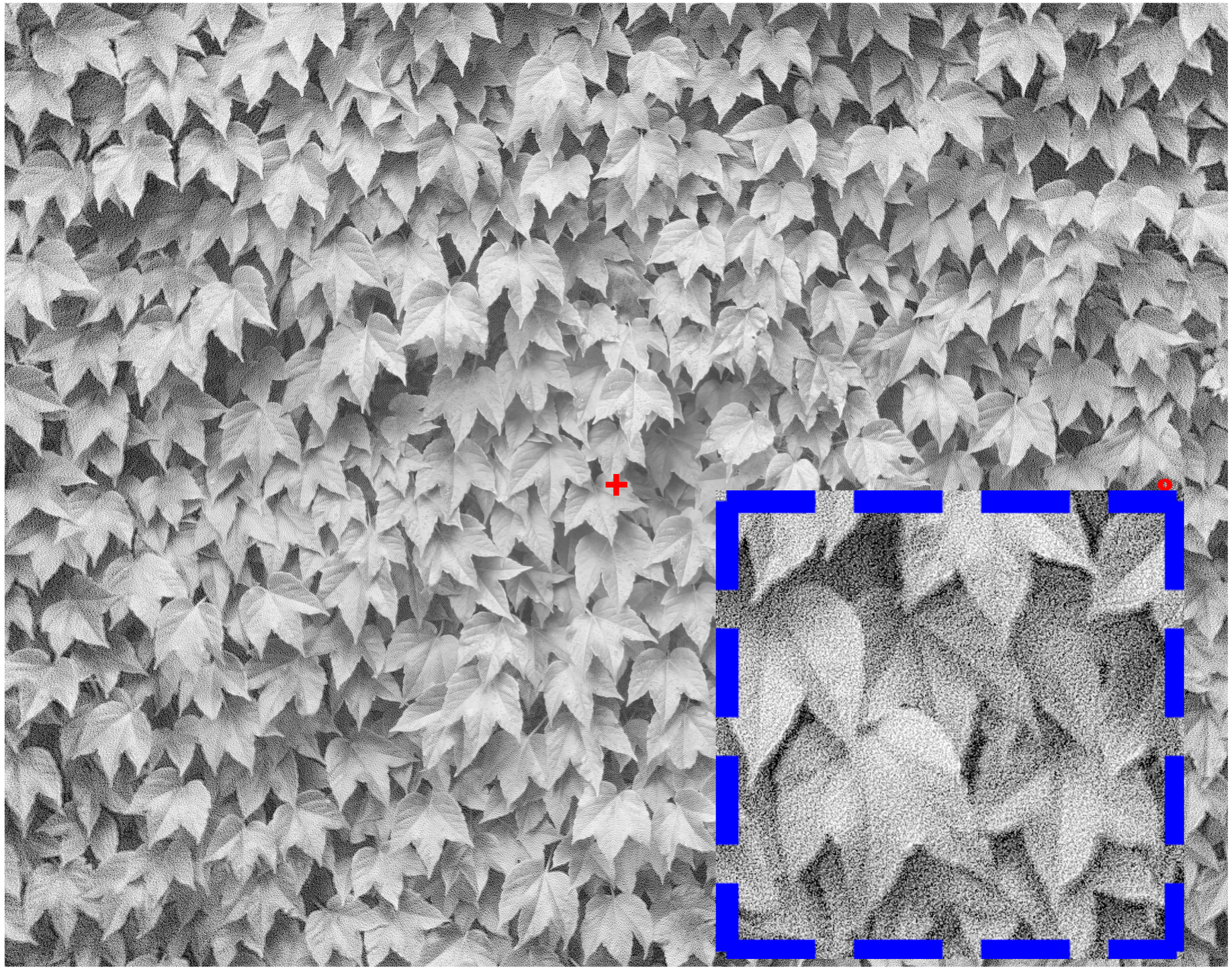
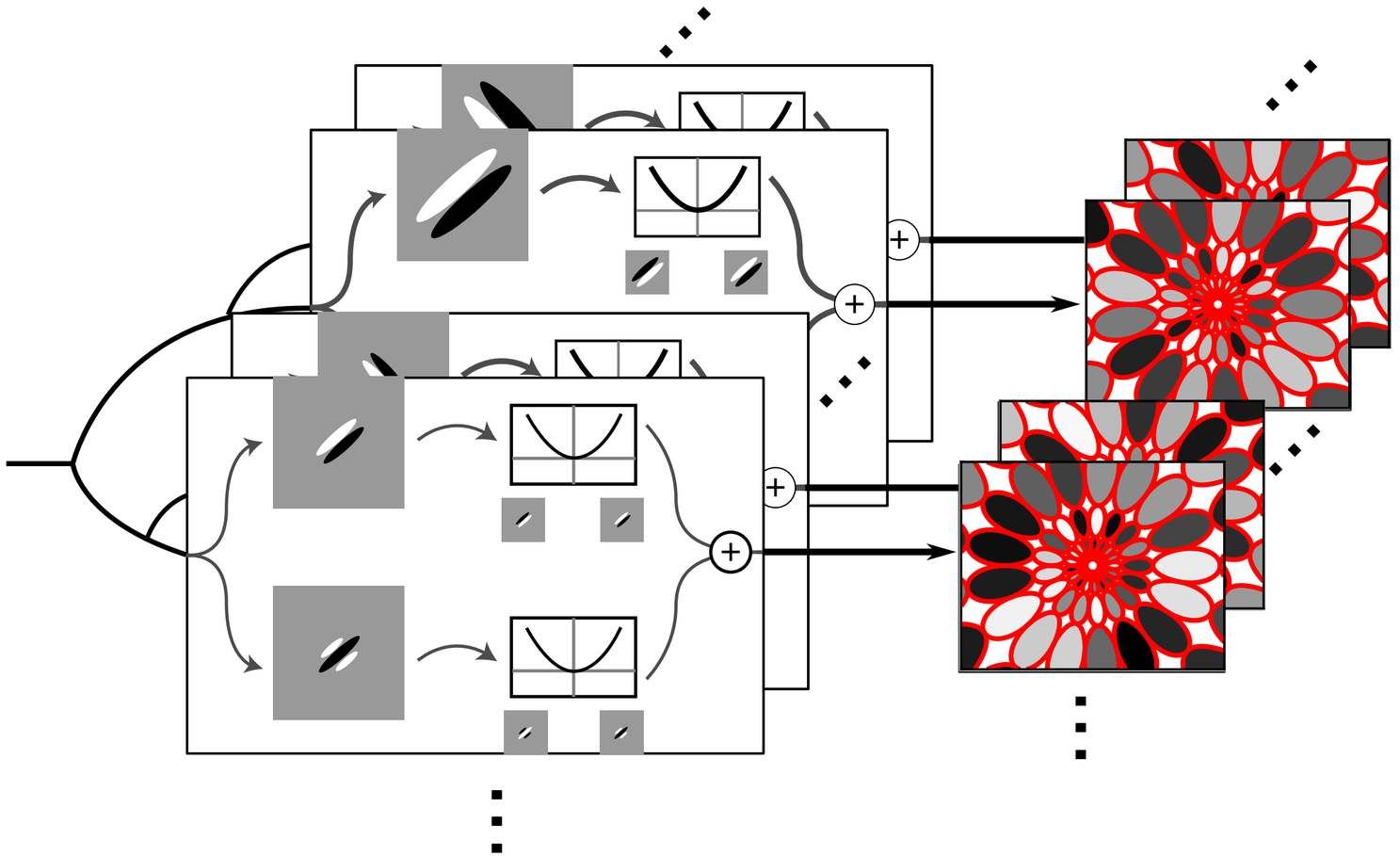
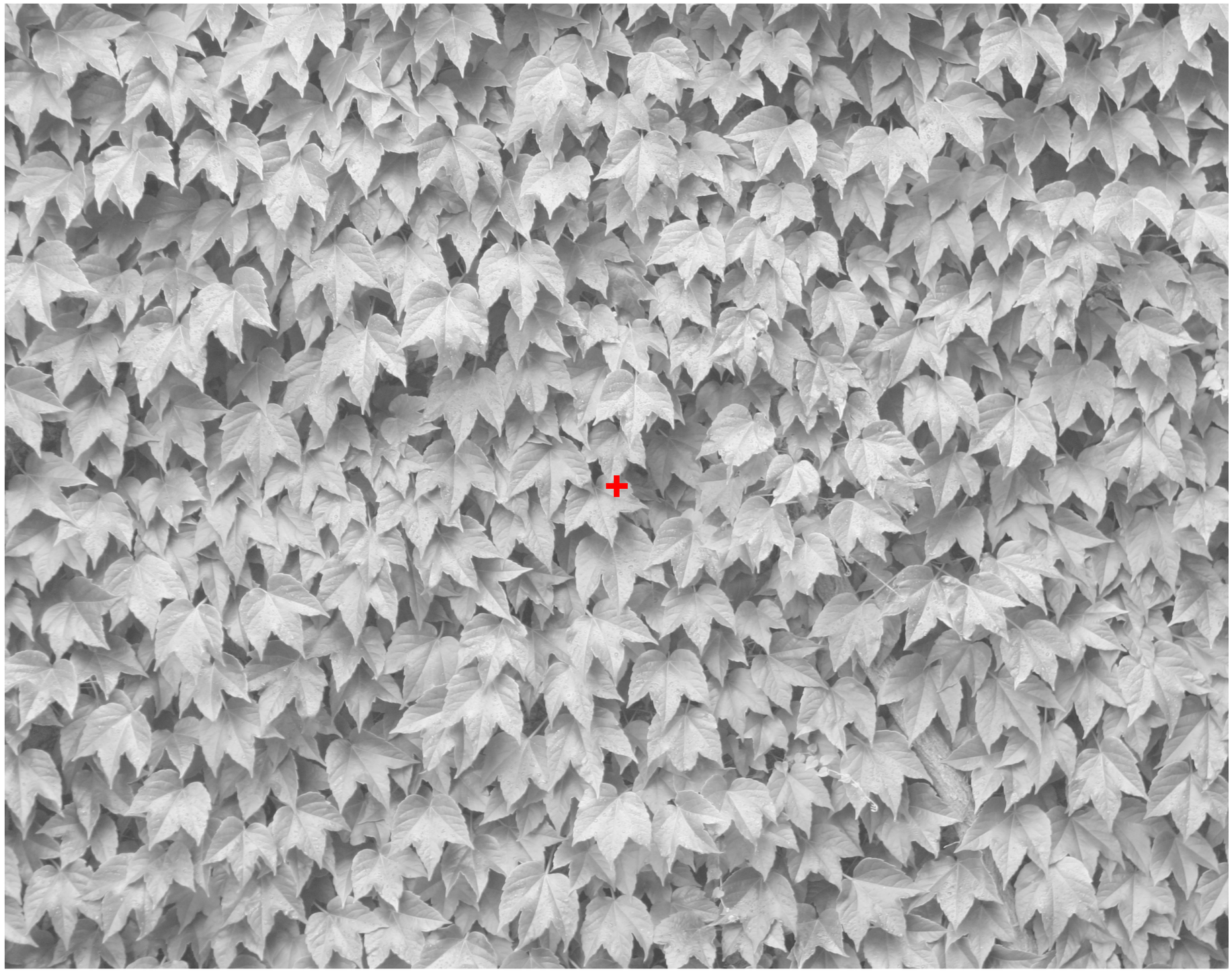
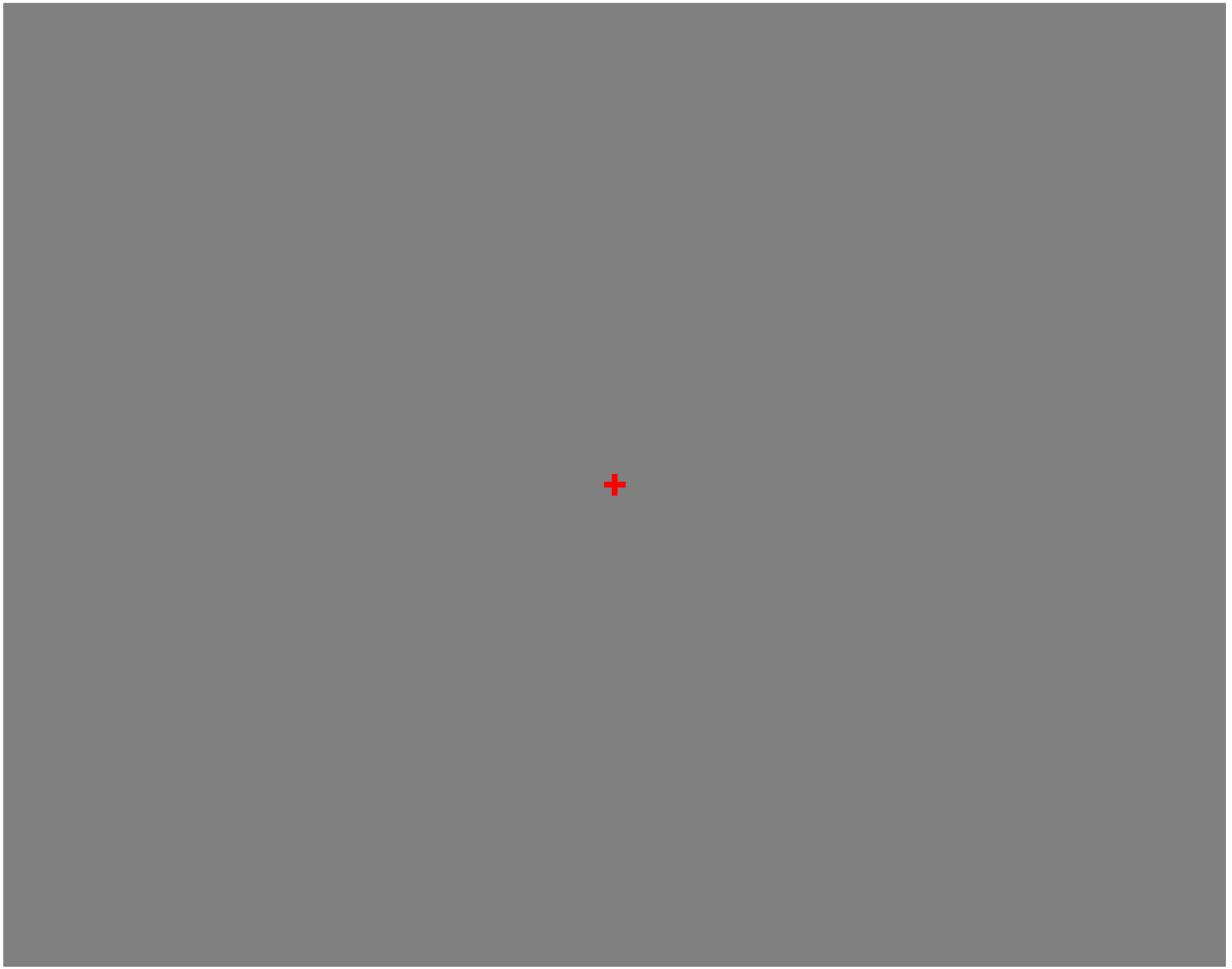


Local spectral energy model



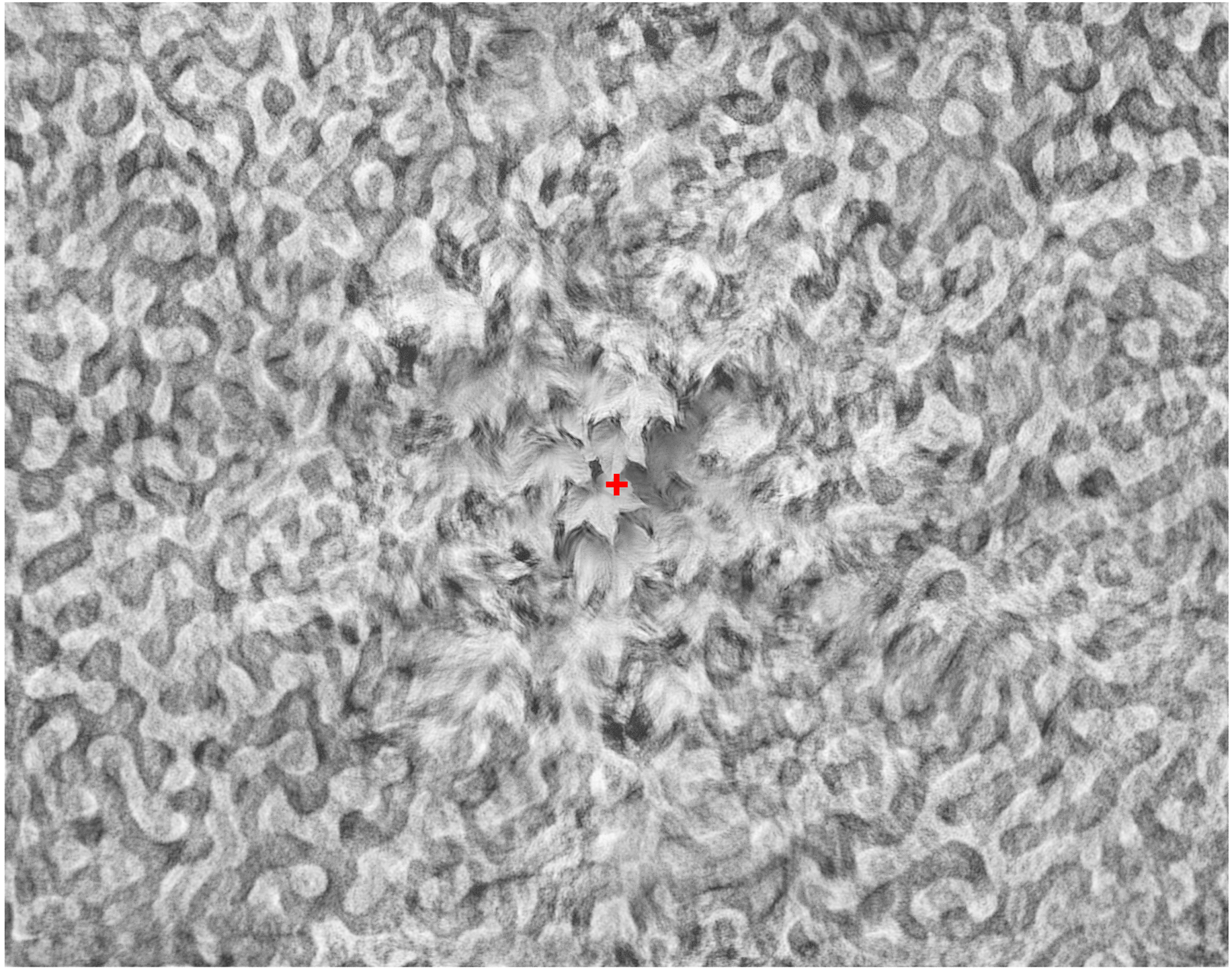
Target Image





Metamer for Energy(0.5)

Not human metamer



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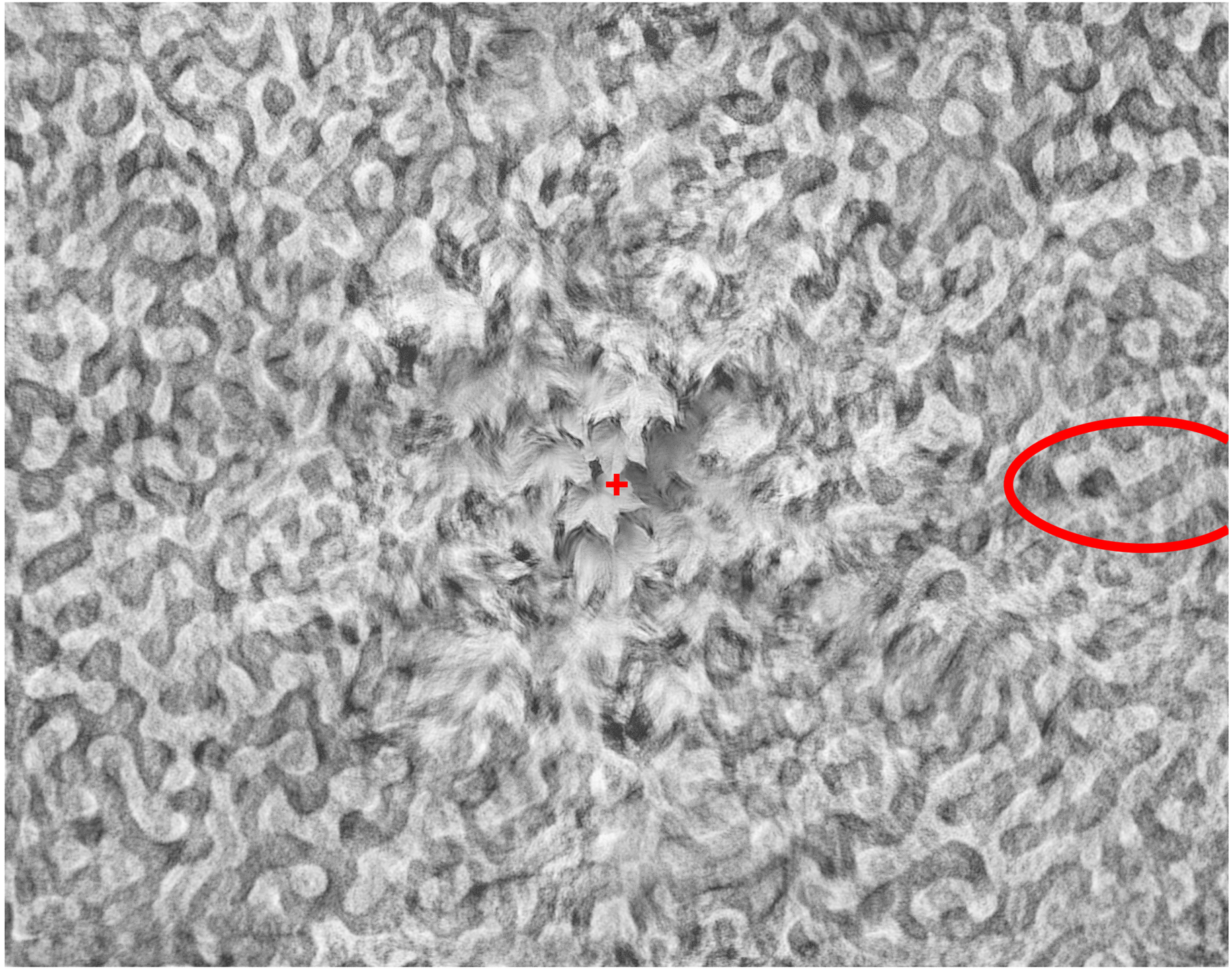
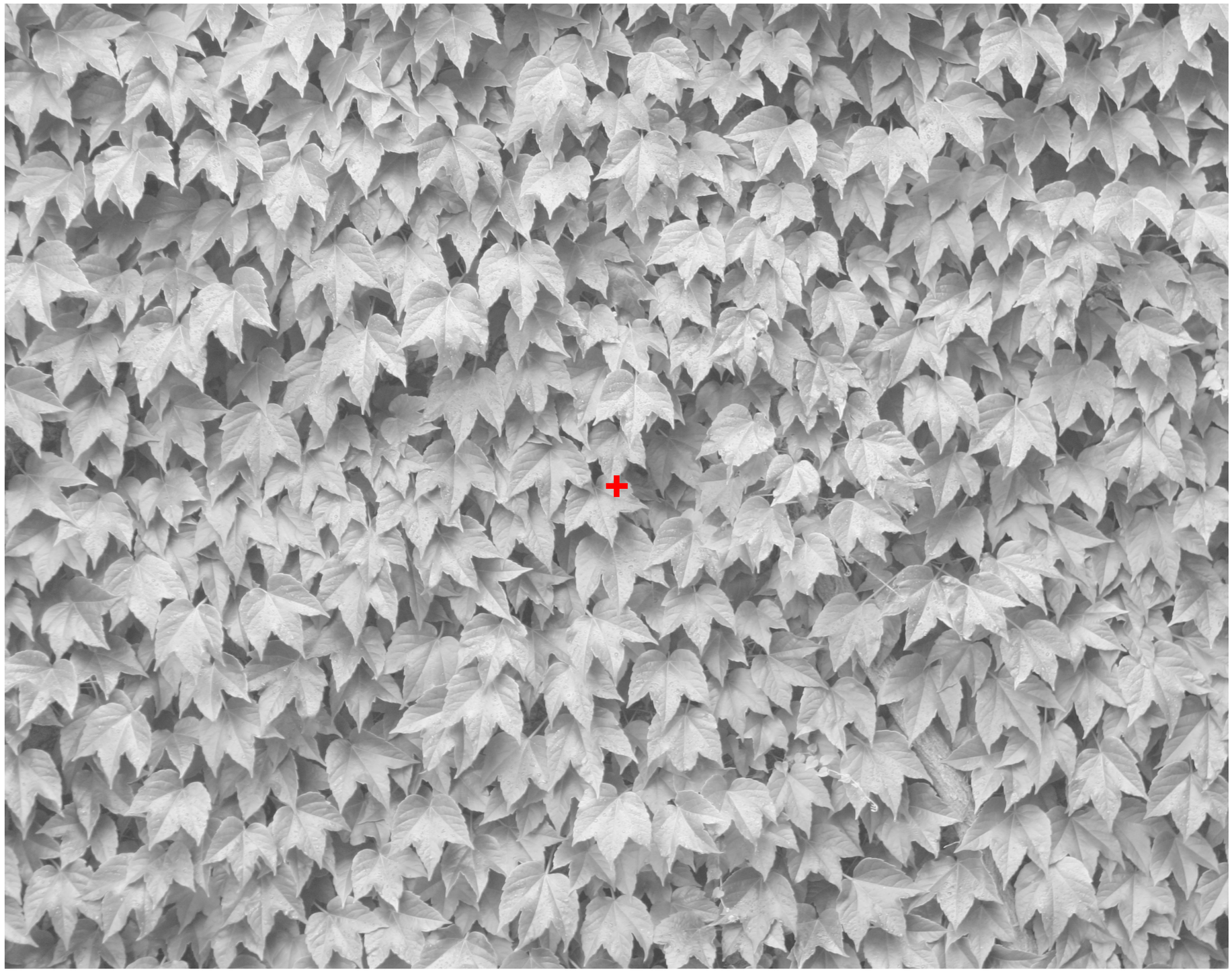
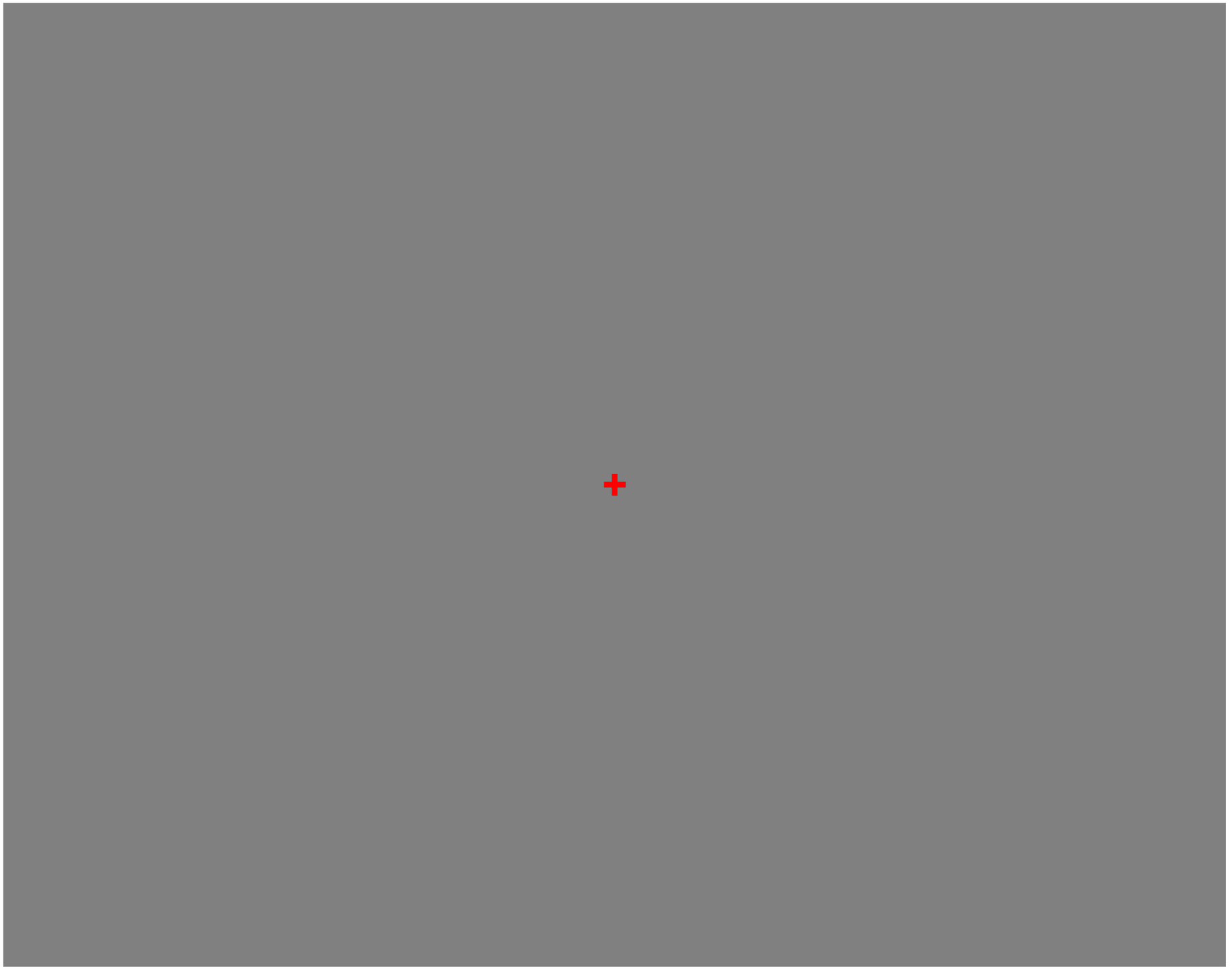


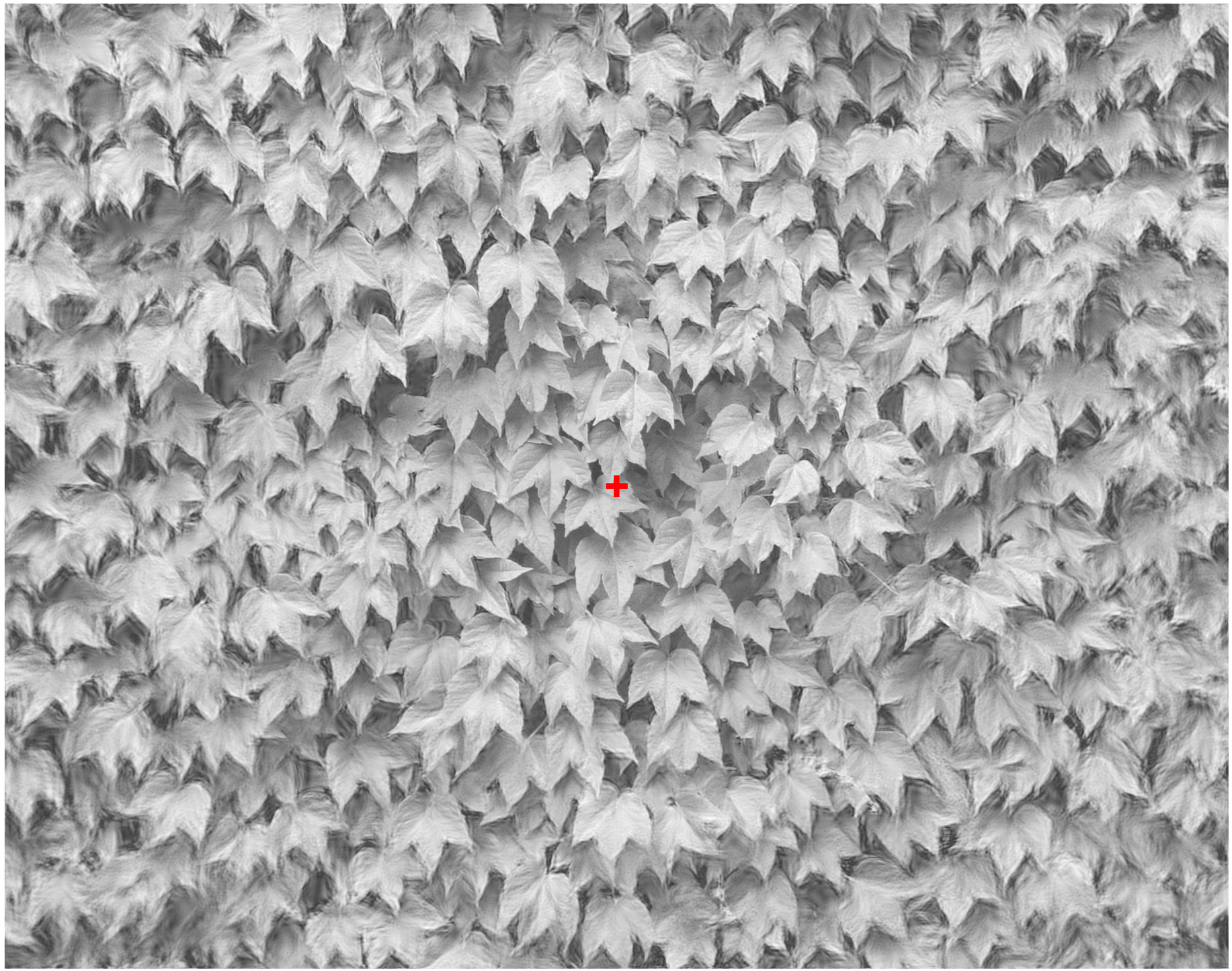
Target Image





Metamer for Energy(~0.06)

Human metamer?



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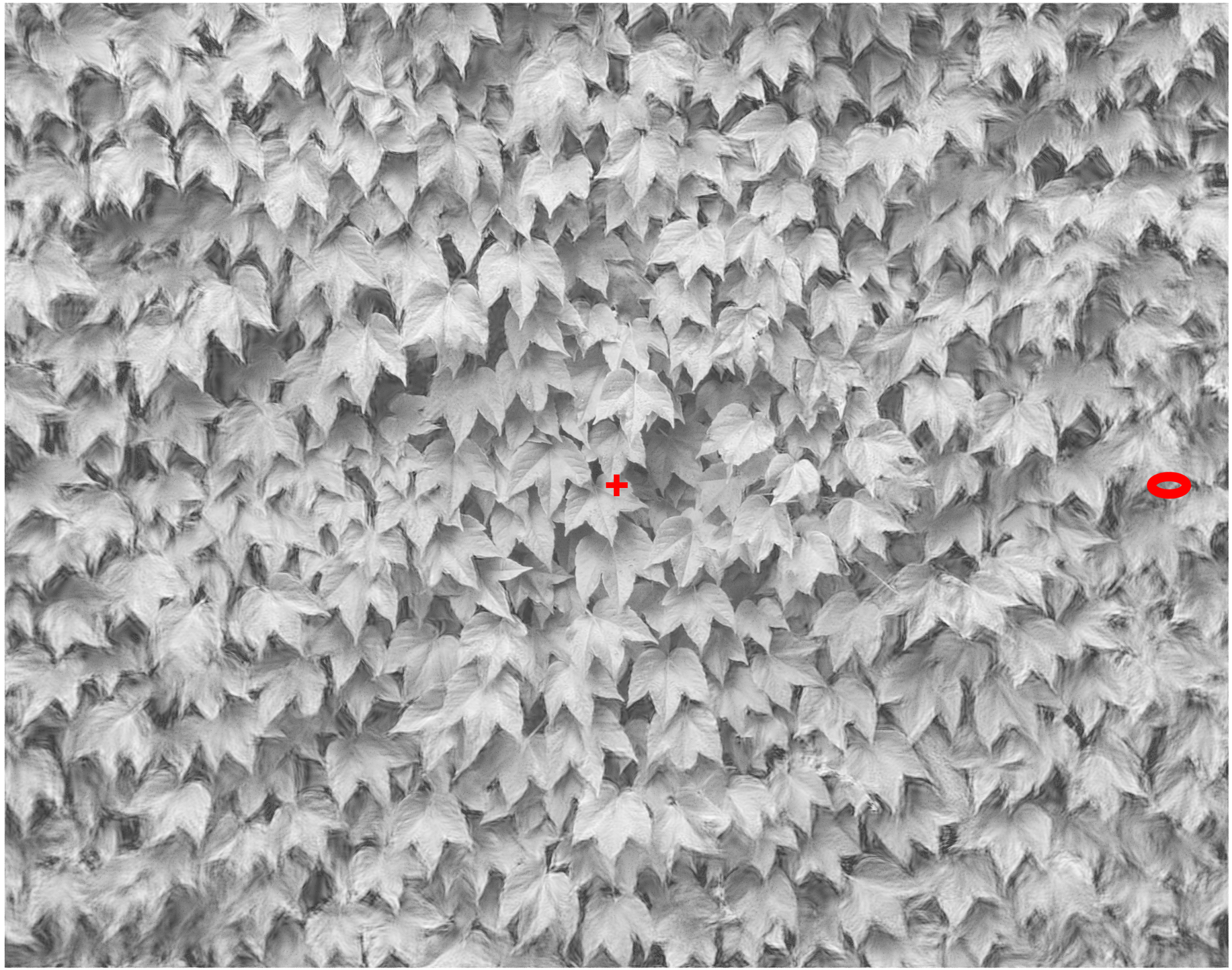

Metamer for Energy(~0.06)

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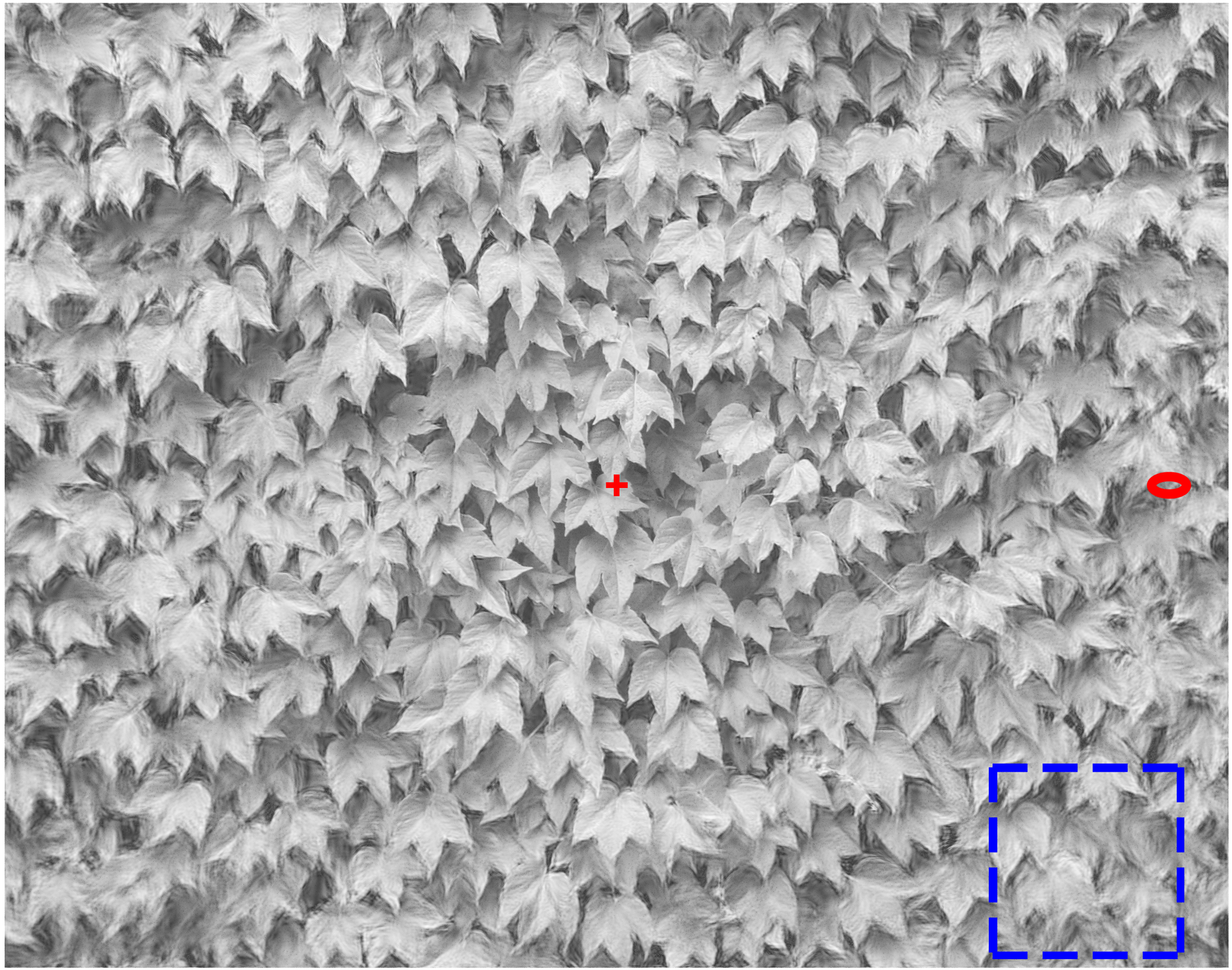
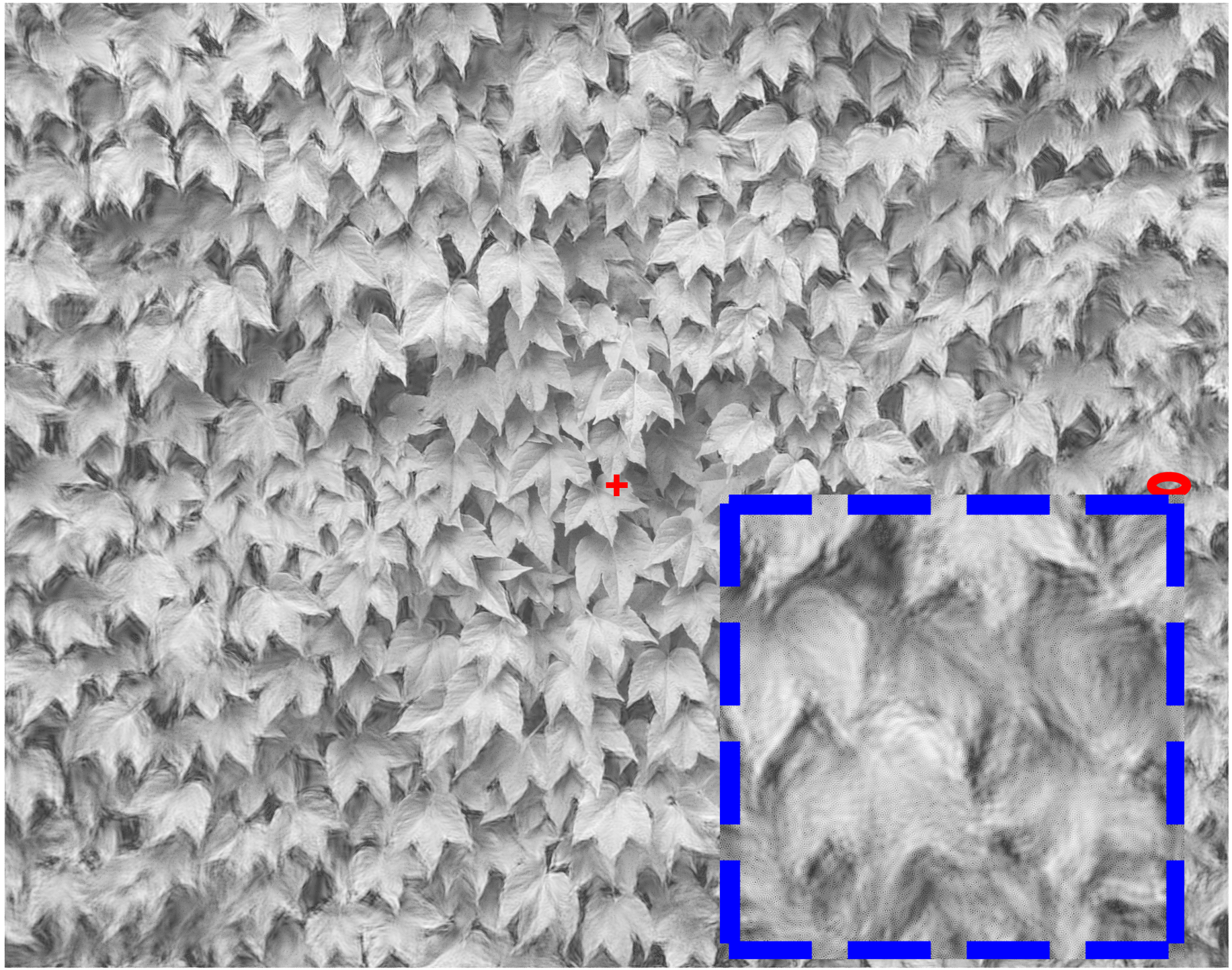


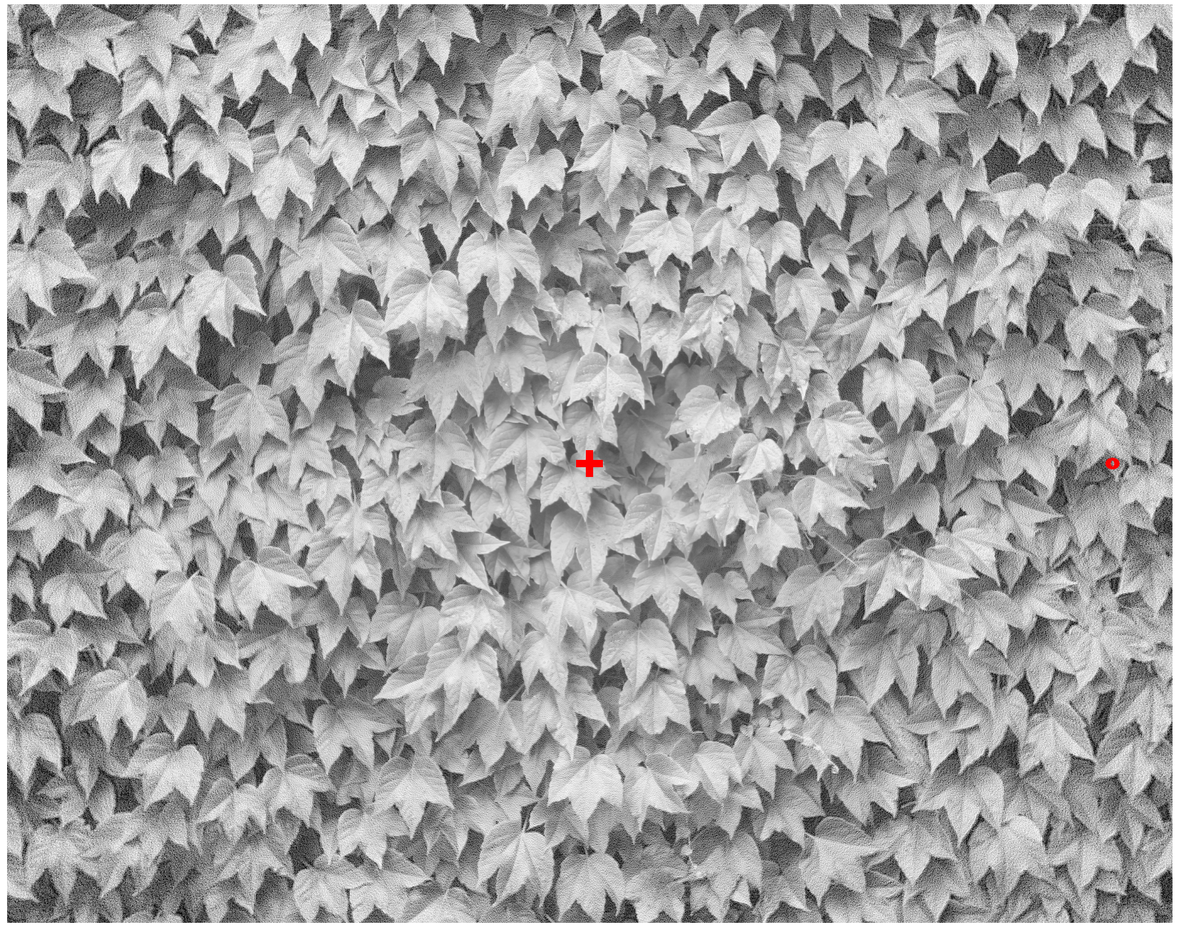
Metamer for Energy(~0.06)

Human metamer?

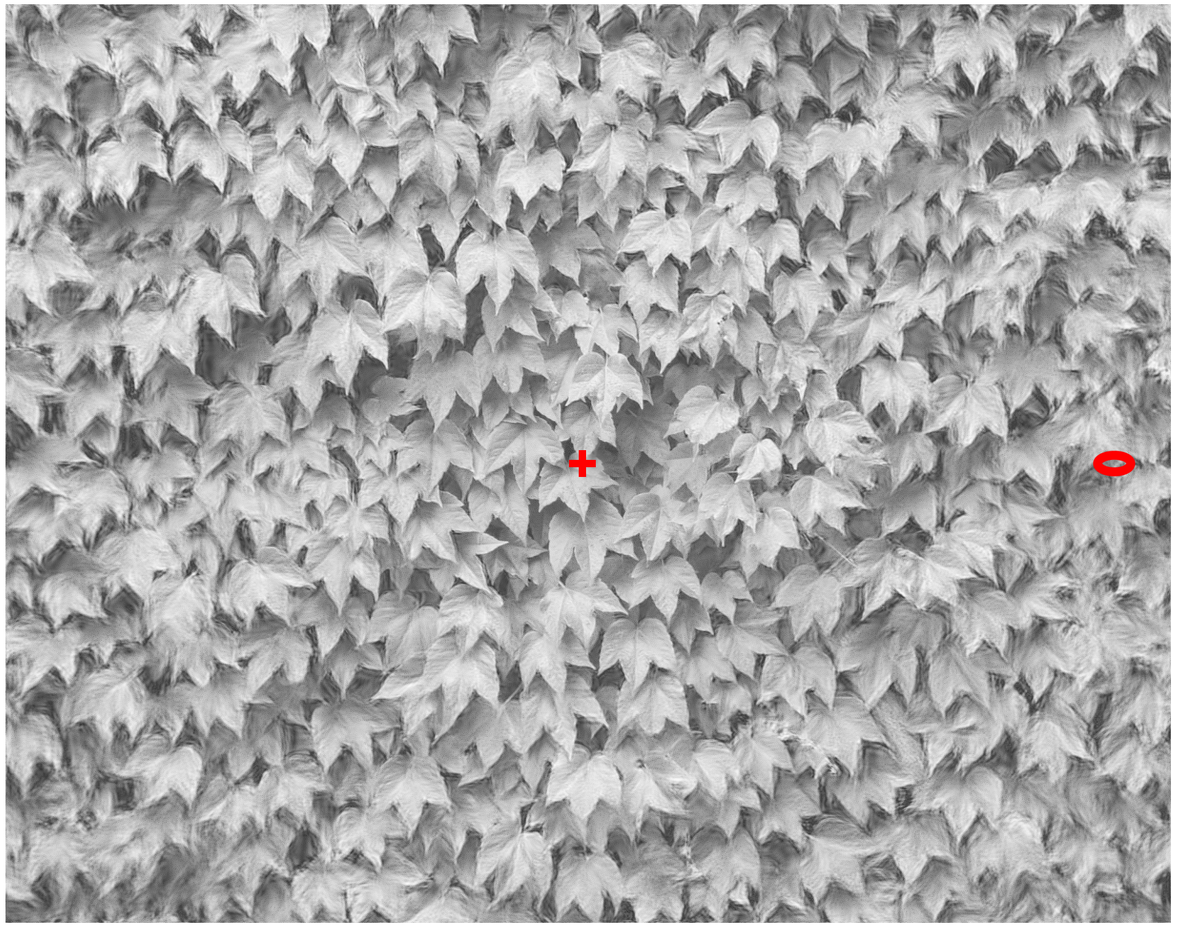


More complex statistics can be pooled over a larger area

Lum(0.01): pixel intensities

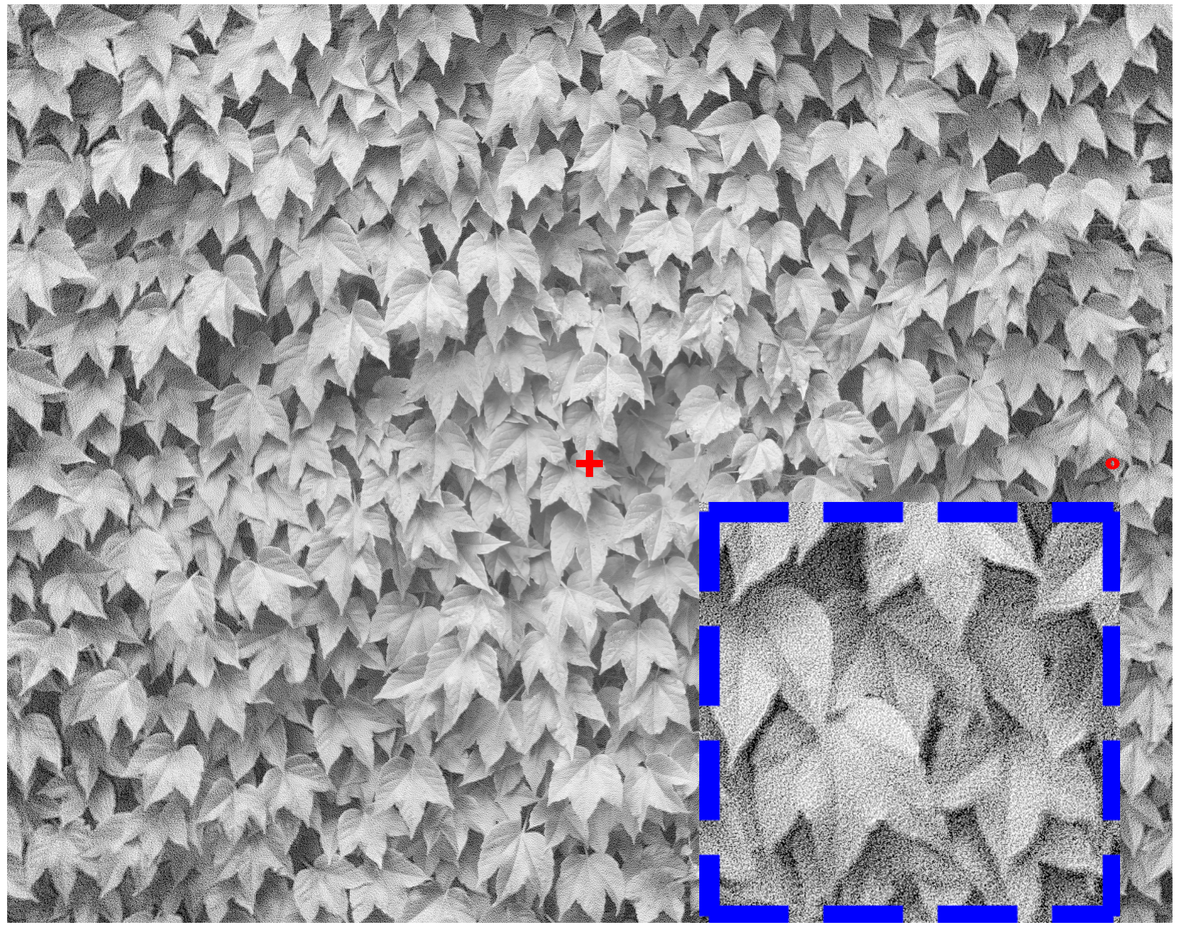


Energy(~0.06): oriented energy

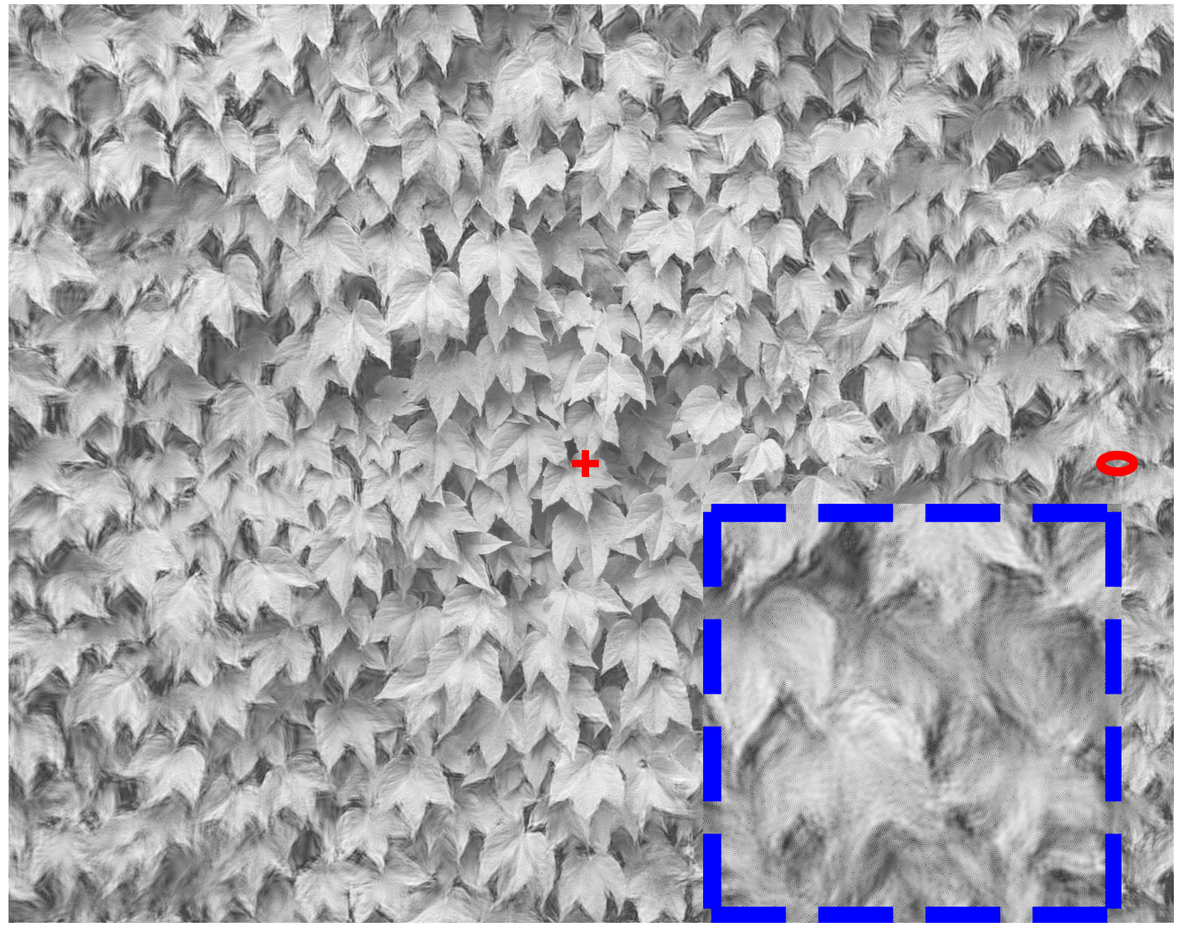


Distortions depend on which statistic is being pooled

Lum(0.01): pixel intensities

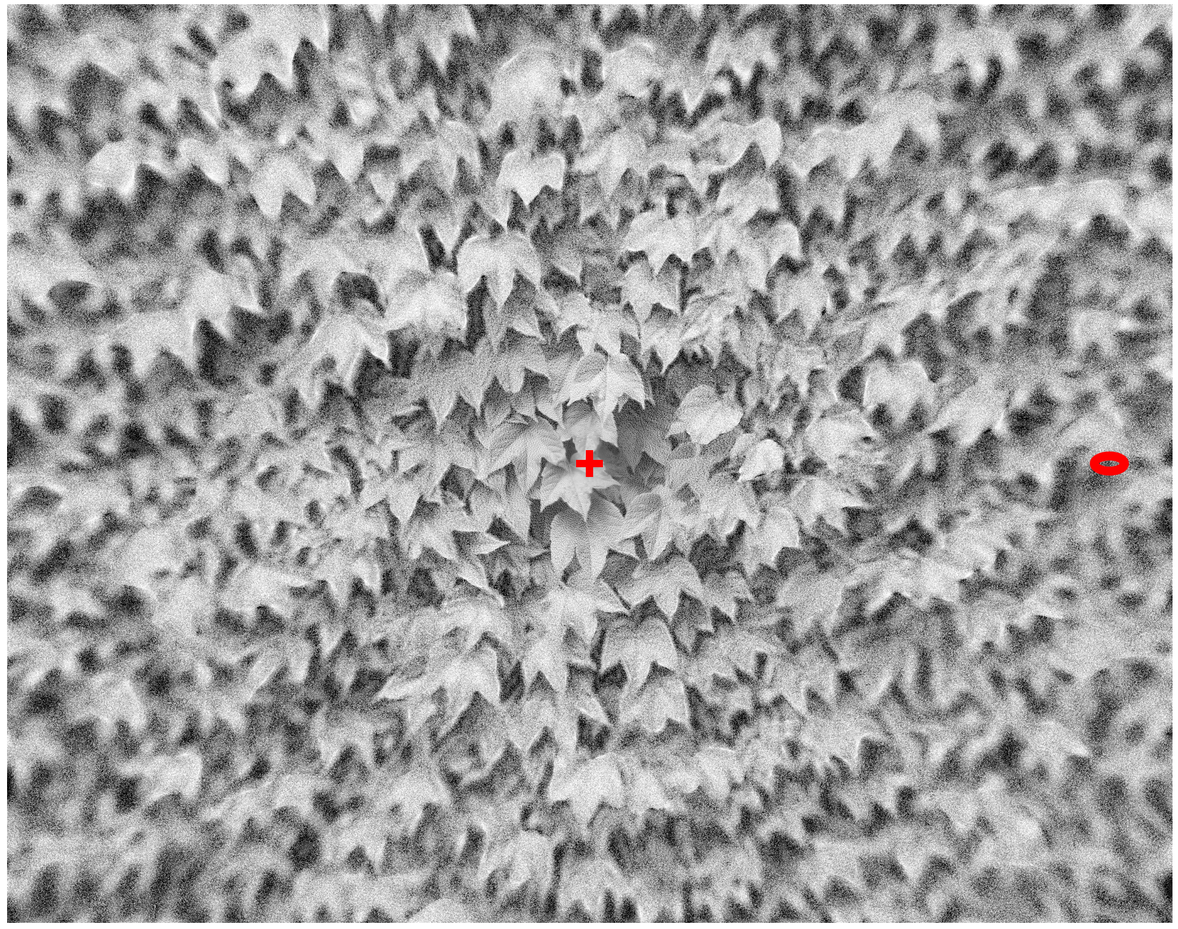


Energy(~0.06): oriented energy

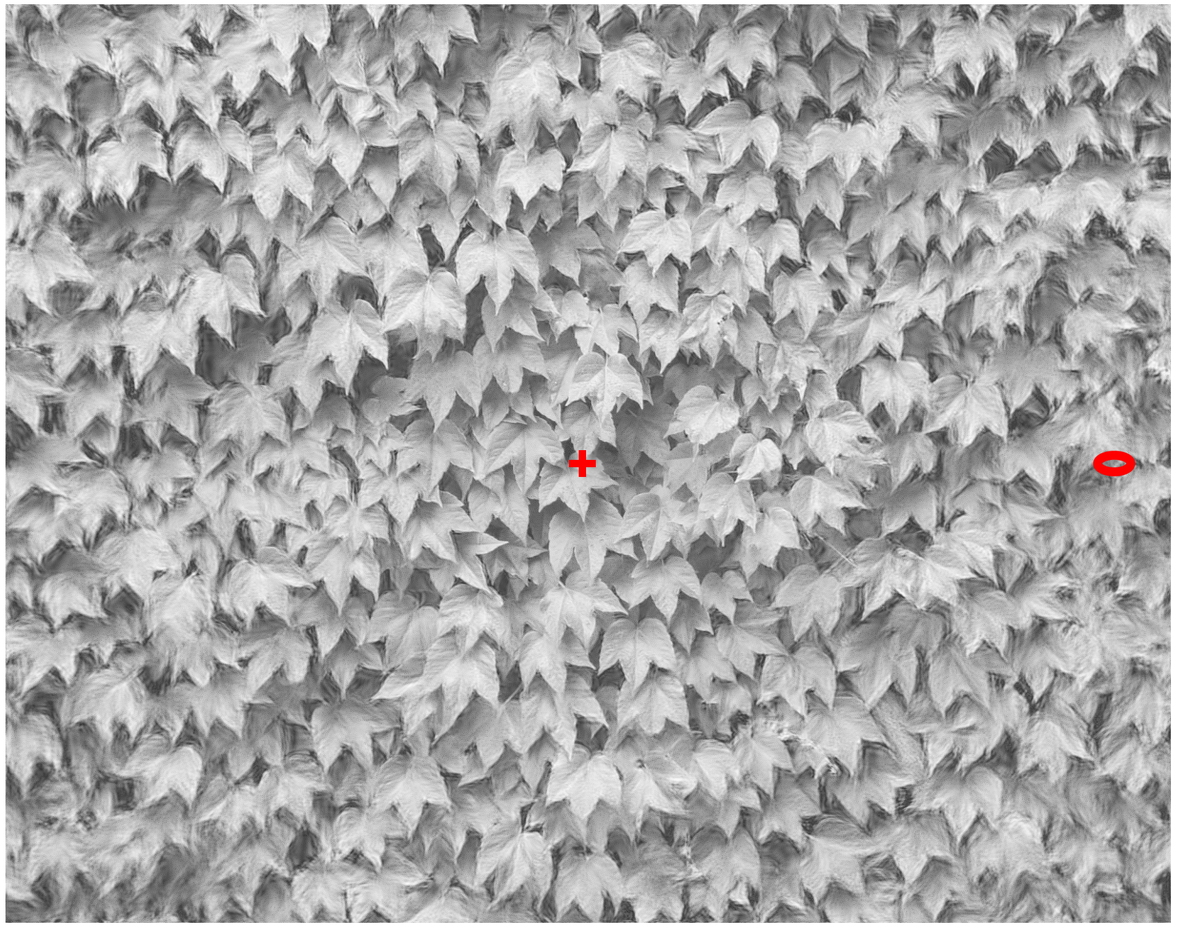


Interaction between statistic and window size is what matters

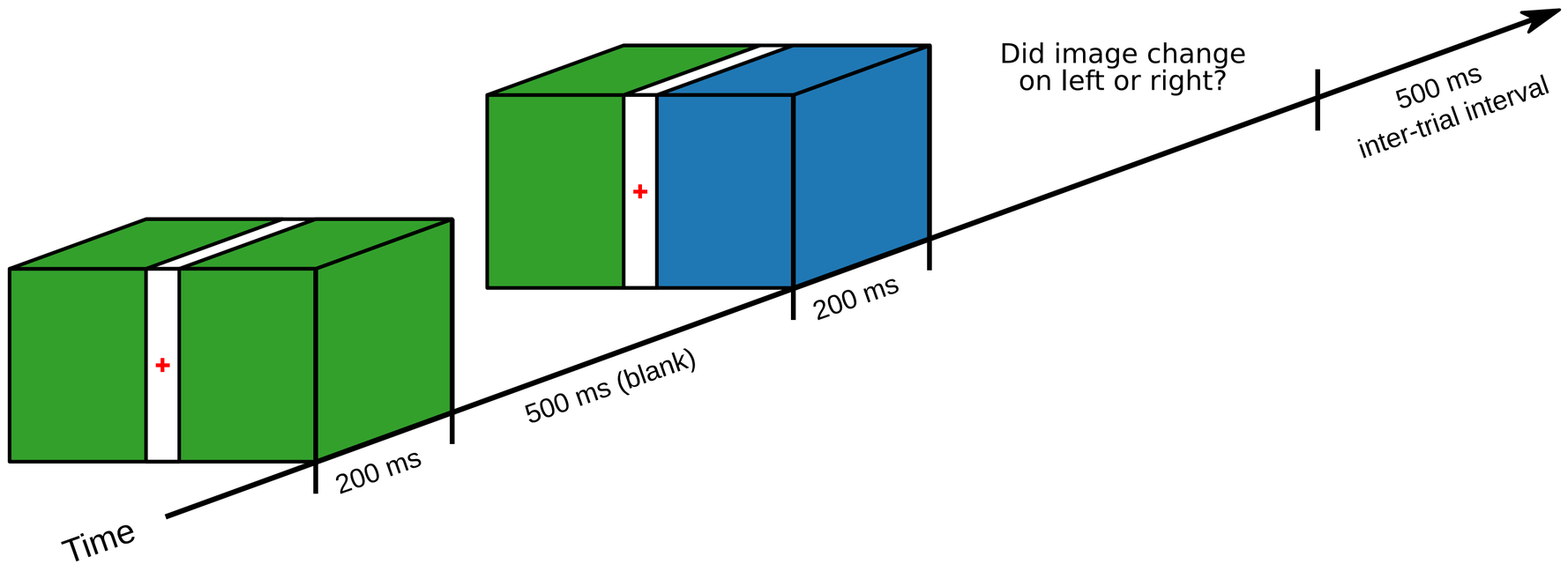
Lum(~0.06): pixel intensities



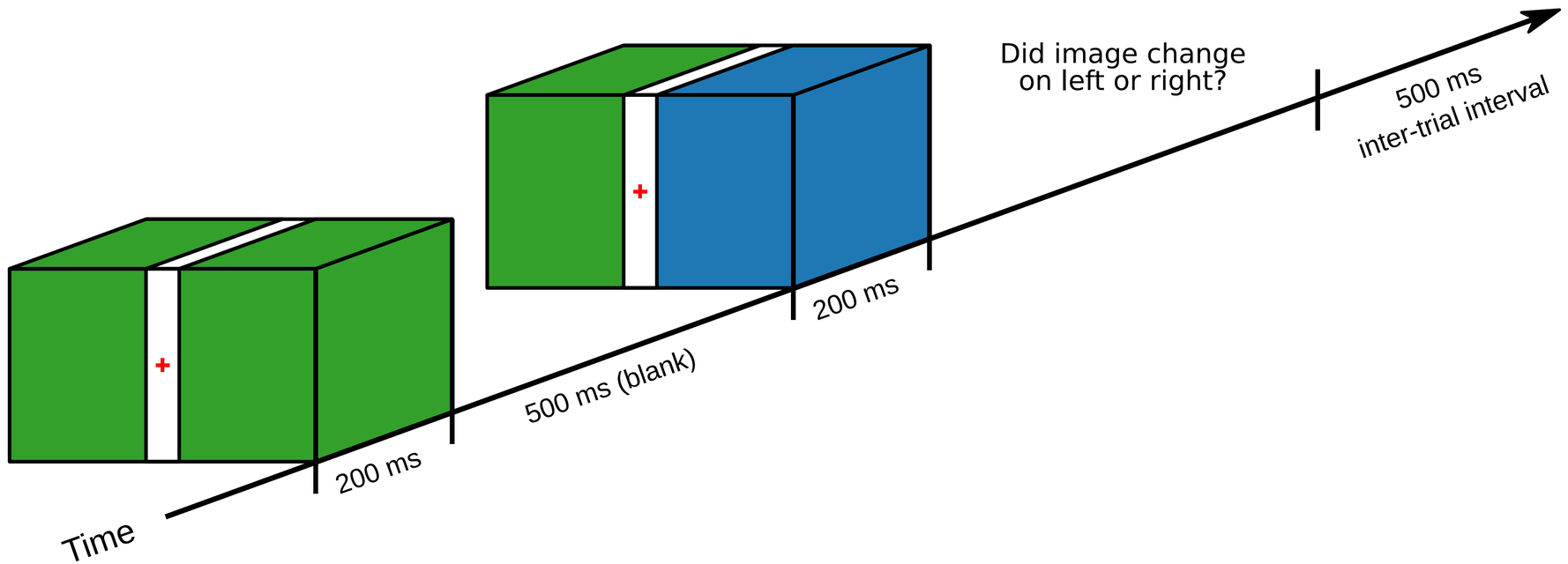
Energy(~0.06): oriented energy



Experiment structure

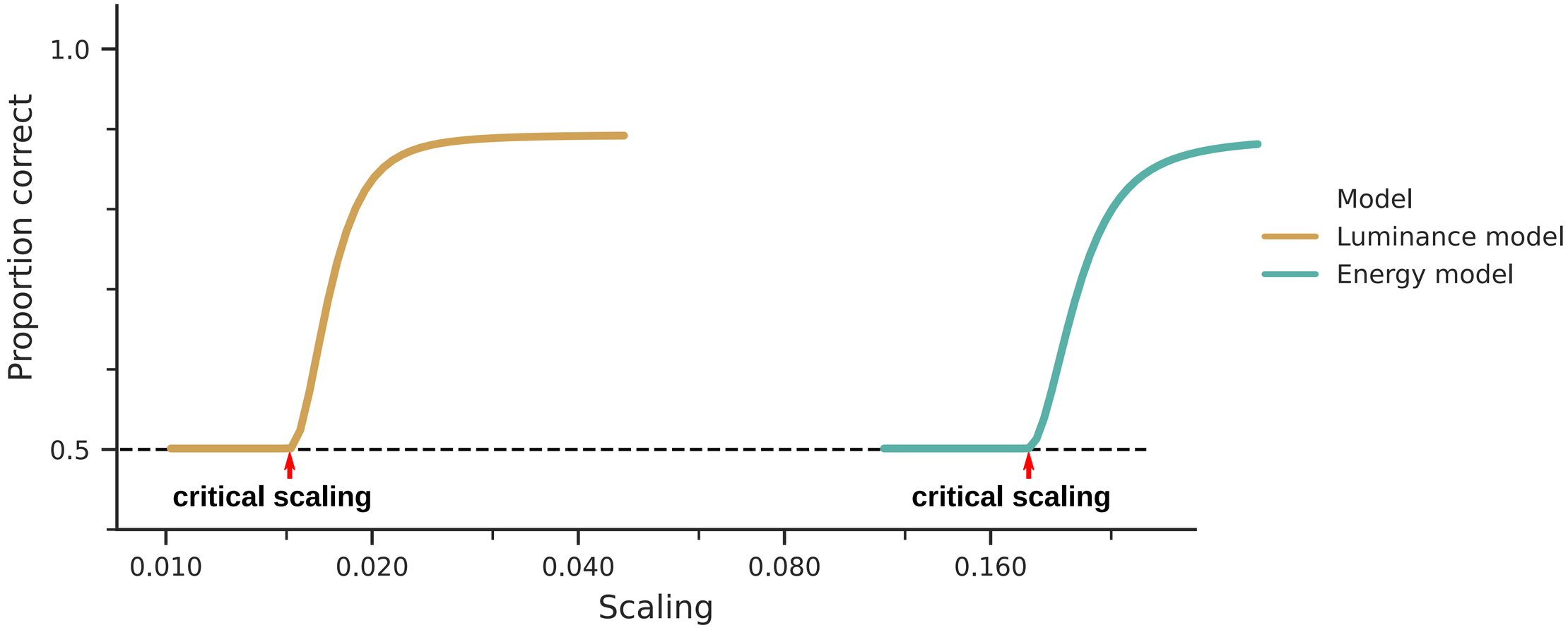


Experiment structure

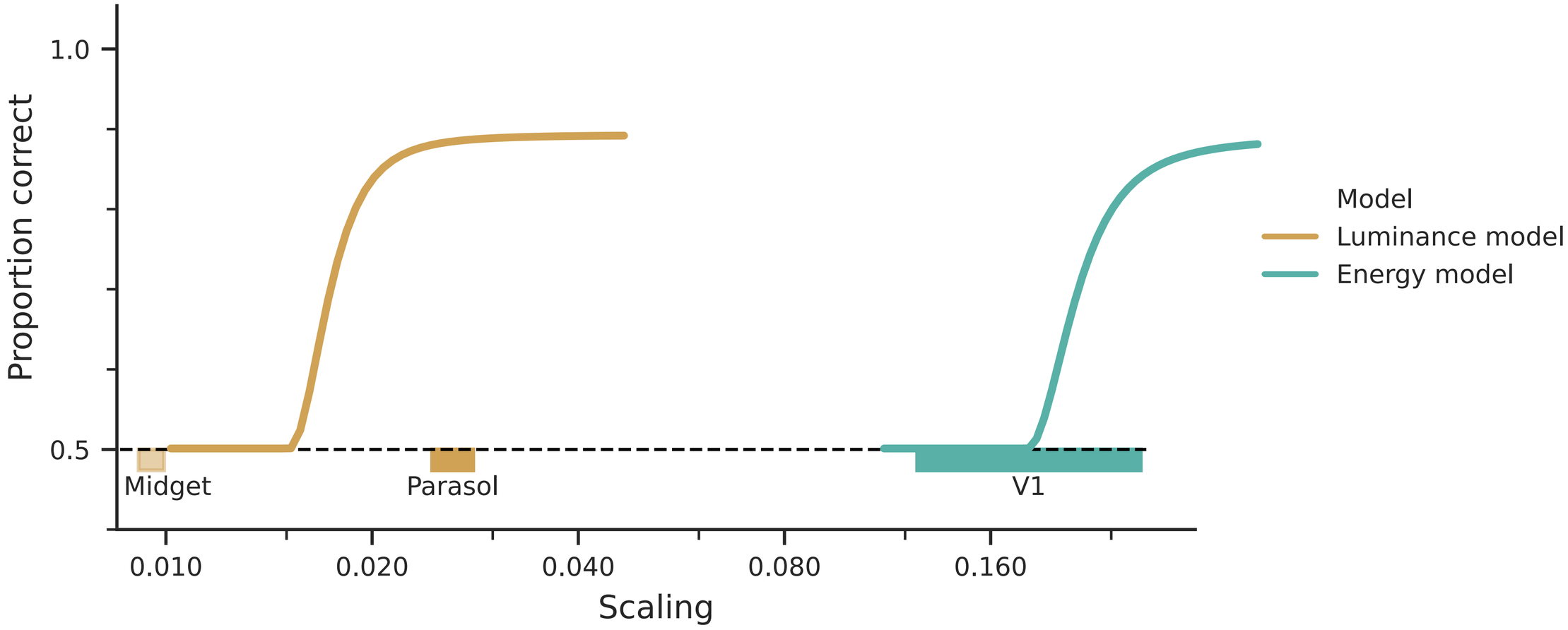


	First image	Second image left	Second image right
Target vs. Metamer	Target	Target	Metamer
		Metamer	Target
	Metamer	Target	Metamer
		Metamer	Target

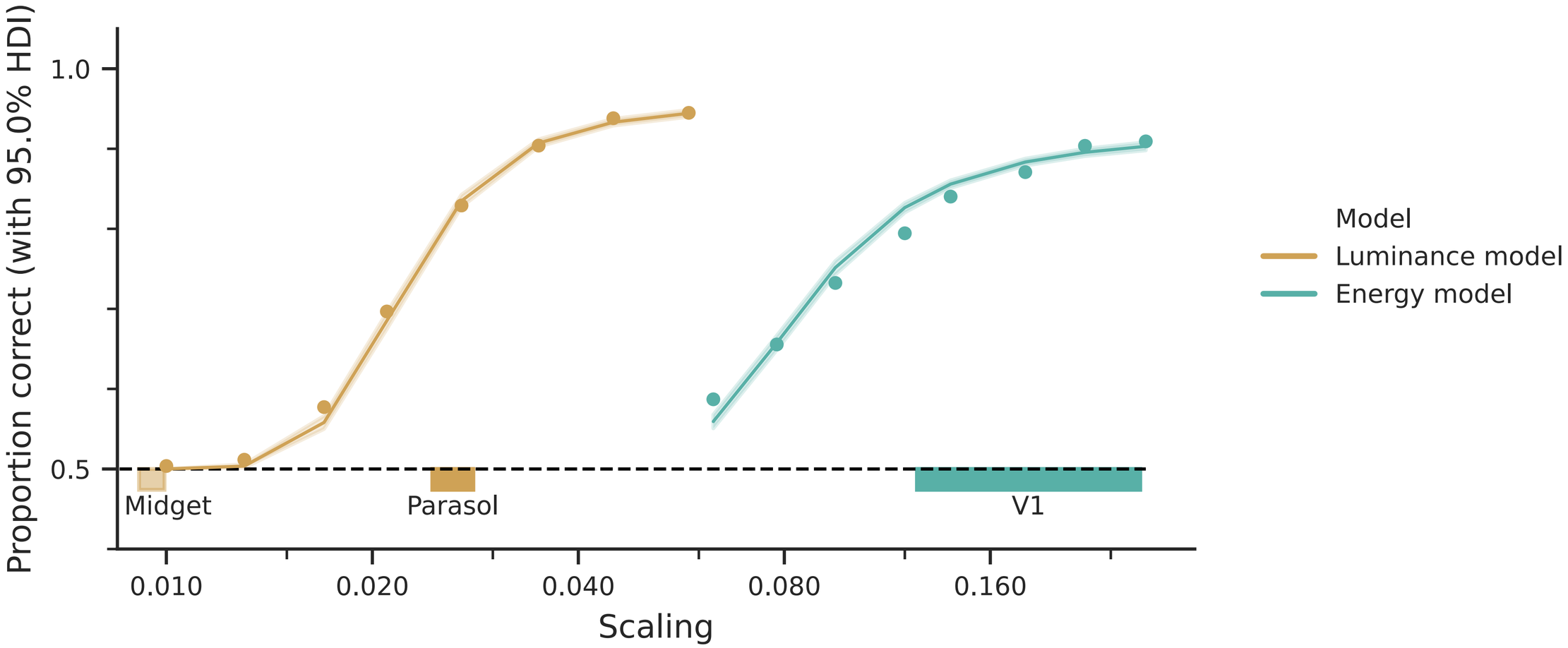
Predictions



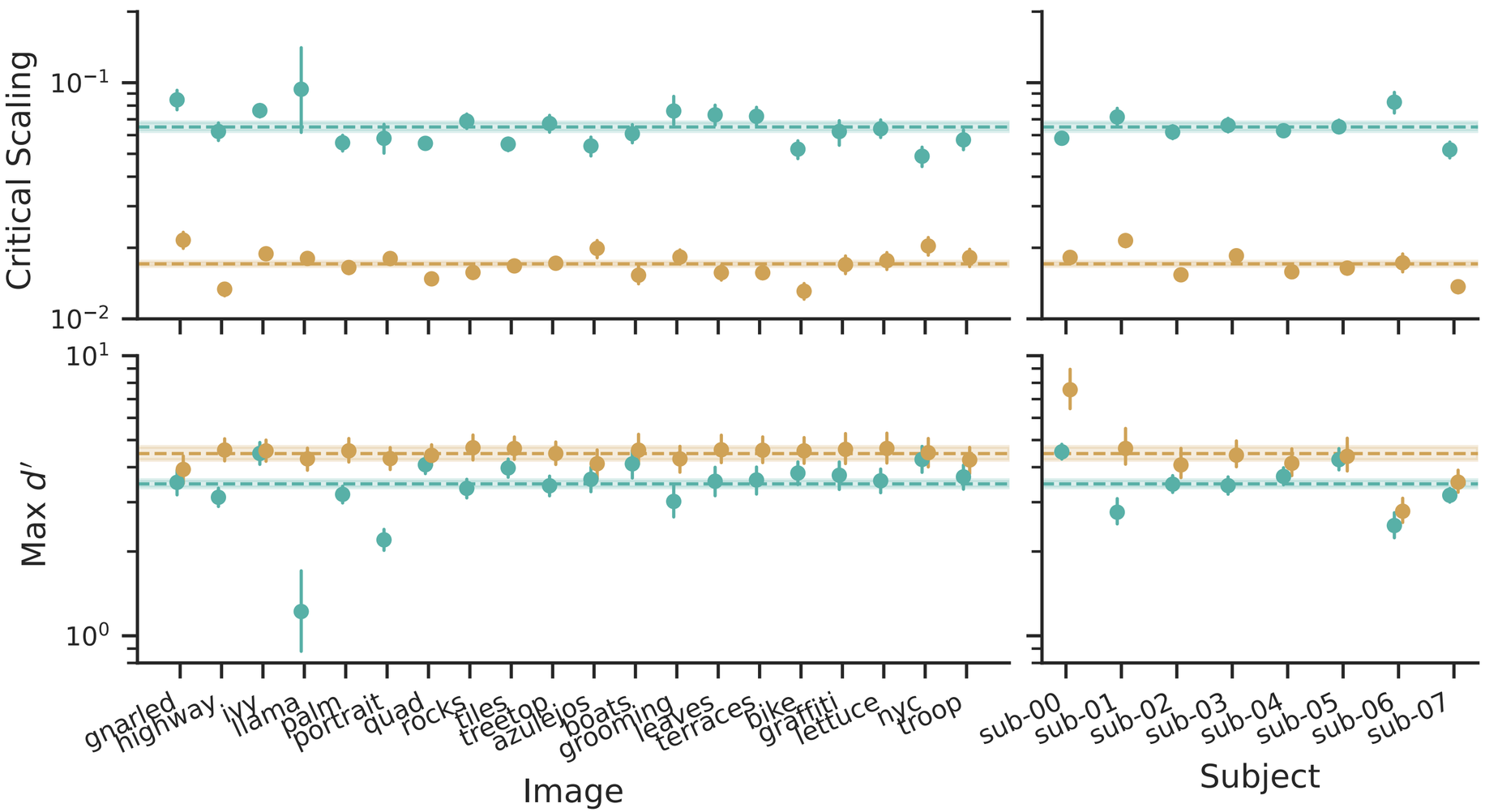
Predictions



Data


Proportion correct (with 95.0% HDI)
1.0
0.5
Midget
Parasol
V1
0.010
0.020
0.040
0.080
0.160
Scaling
Model
Luminance model
Energy model

Parameters


Critical Scaling
10^{-1}
10^{-2}
Max d'
10^{1}
10^{0}
gnarled
highway
ivy
llama
palm
portrait
quad
rocks
tiles
treetop
azulejos
boats
grooming
leaves
terraces
bike
graffiti
lettuce
nyc
troop
Image
sub-00
sub-01
sub-02
sub-03
sub-04
sub-05
sub-06
sub-07
Subject

Intermediate conclusions

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  https://users.flatironinstitute.org/~wbroderick/metamers/

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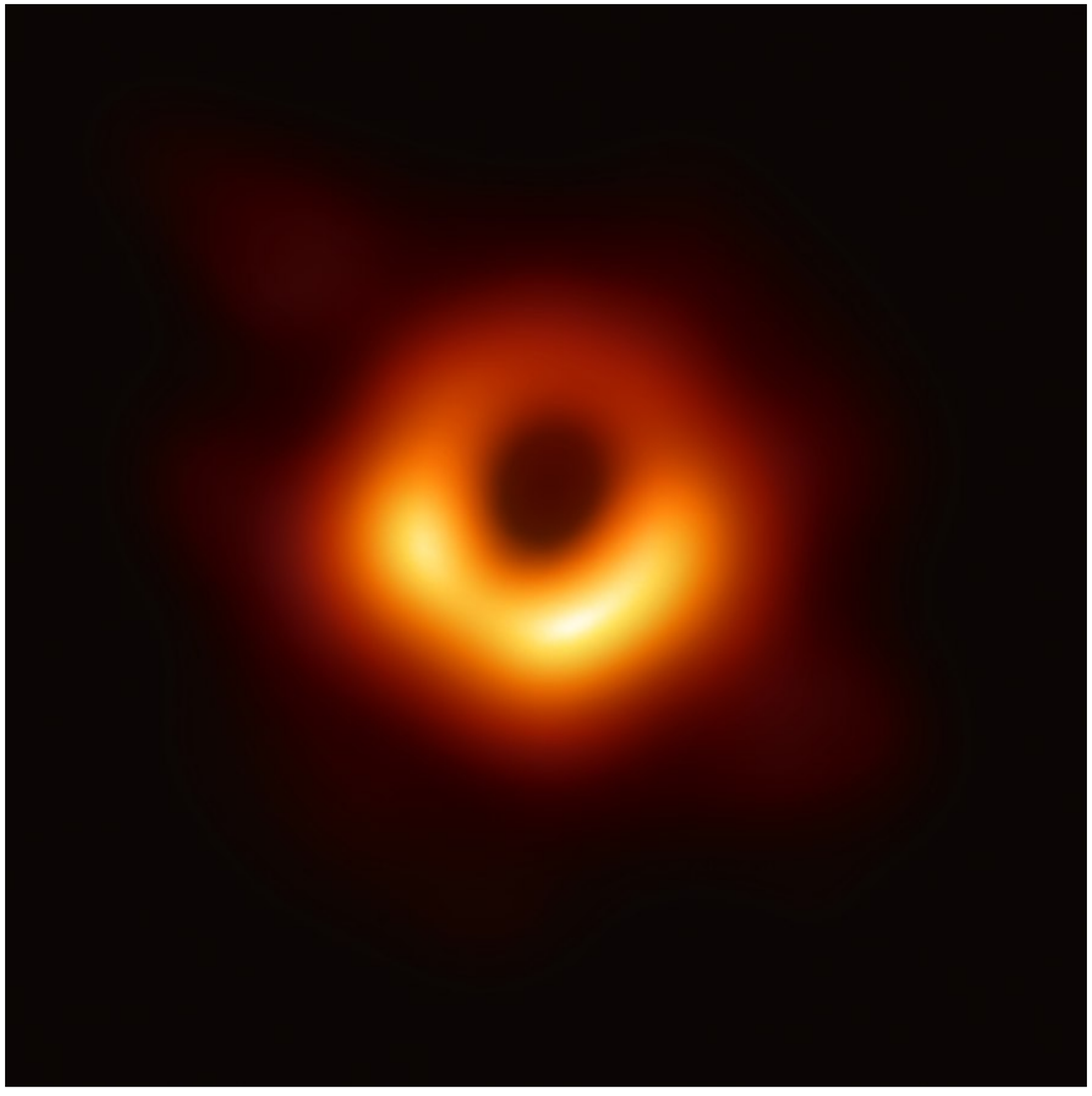
- Ran psychophysics experiment to find each model's critical scaling
- Showed spatial scale of pooling grows with statistic complexity

Open Science!



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By SETH BORENSTEIN April 10, 2019

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'Like looking at the gates of Hell': Astronomers just revealed the first picture of a black hole, and it's a monster

Dave Mosher Apr 10, 2019, 9:46 AM

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Scientists unveil first image of black hole in all its dark glory

BY WILLIAM HARWOOD

UPDATED ON: APRIL 10, 2019 / 8:58 PM / CBS NEWS

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April 10, 2019 · 8:56 AM ET

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The New York Times

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Astronomers at last have captured a picture of one of the secretive entities in the cosmos.

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Earth Sees First Image Of A Black Hole

April 10, 2019 · 8:56 AM ET

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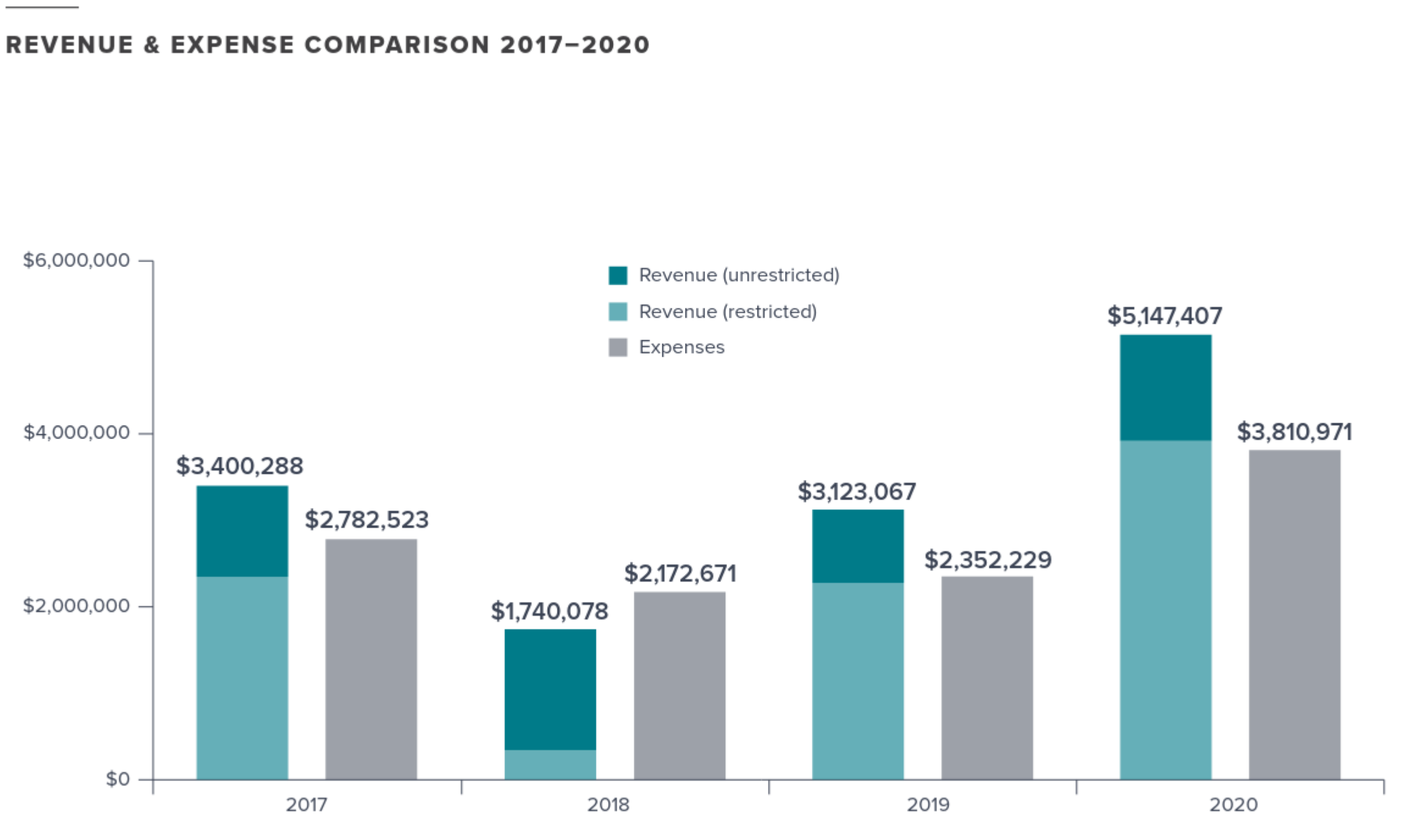
Insufficient Impact

Software is under-funded



[NumFOCUS 2020 Annual Report]

Software is under-funded

NIH Awards by Location & Organization

FROZEN

Explore year-by-year NIH funding by institution, state, congressional district, and more!

Data frozen as of 10/16/2020. Data released on 1/8/2021.

...

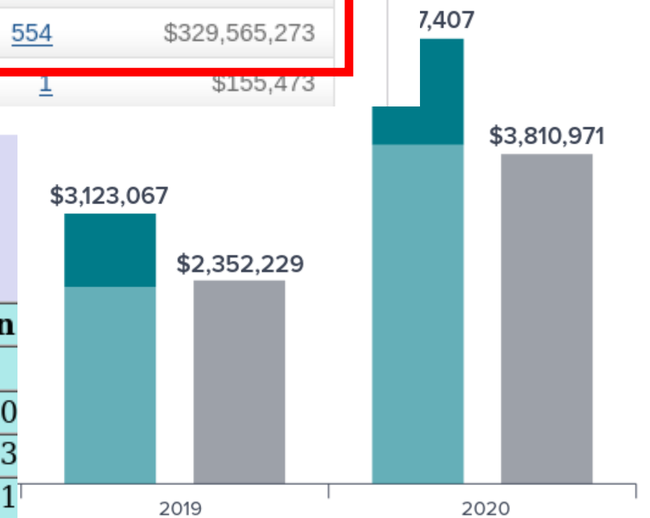
NEOCHROMOSOME, INC.	New York	NY	UNITED STATES	1	$300,000
NEW YORK BLOOD CENTER	NEW YORK	NY	UNITED STATES	15	$12,135,659
NEW YORK UNIVERSITY	NEW YORK	NY	UNITED STATES	188	$77,336,088
NEW YORK UNIVERSITY SCHOOL OF MEDICINE	NEW YORK	NY	UNITED STATES	554	$329,565,273
ONEGEVITY HEALTH LLC	NEW YORK	NY	UNITED STATES	1	$155,473

Award Summary: Top 200 Institutions FY 2020
Managing Organization: NSF
Funding Organization: NSF
Institution Type: All Groups

Institution (200 max)	State or Country	Total		Research Support		Education & Human
(Drill to Awards)		Amt $k	Cnt	Amt $k	Cnt	Amt $k
Leidos	Maryland	$231,869	1	$183,593	1	$0
U of Ill Urbana-Champaign	Illinois	$141,492	265	$135,139	253	$6,353
UCAR	Colorado	$138,351	40	$137,580	38	$771
AURA	District of Columbia	$127,312	9	$80,963	8	$0
Regents U of Michigan	Michigan	$120,055	329	$102,987	307	$17,068

...

University of Virginia	Virginia	$41,687	129	$37,450	124	$4,238
New York University	New York	$41,567	144	$37,685	134	$3,882
SUNY Stony Brook	New York	$41,411	121	$39,563	117	$1,848



[NumFOCUS 2020 Annual Report]

… but heavily-used

- 92% of British academics use research software
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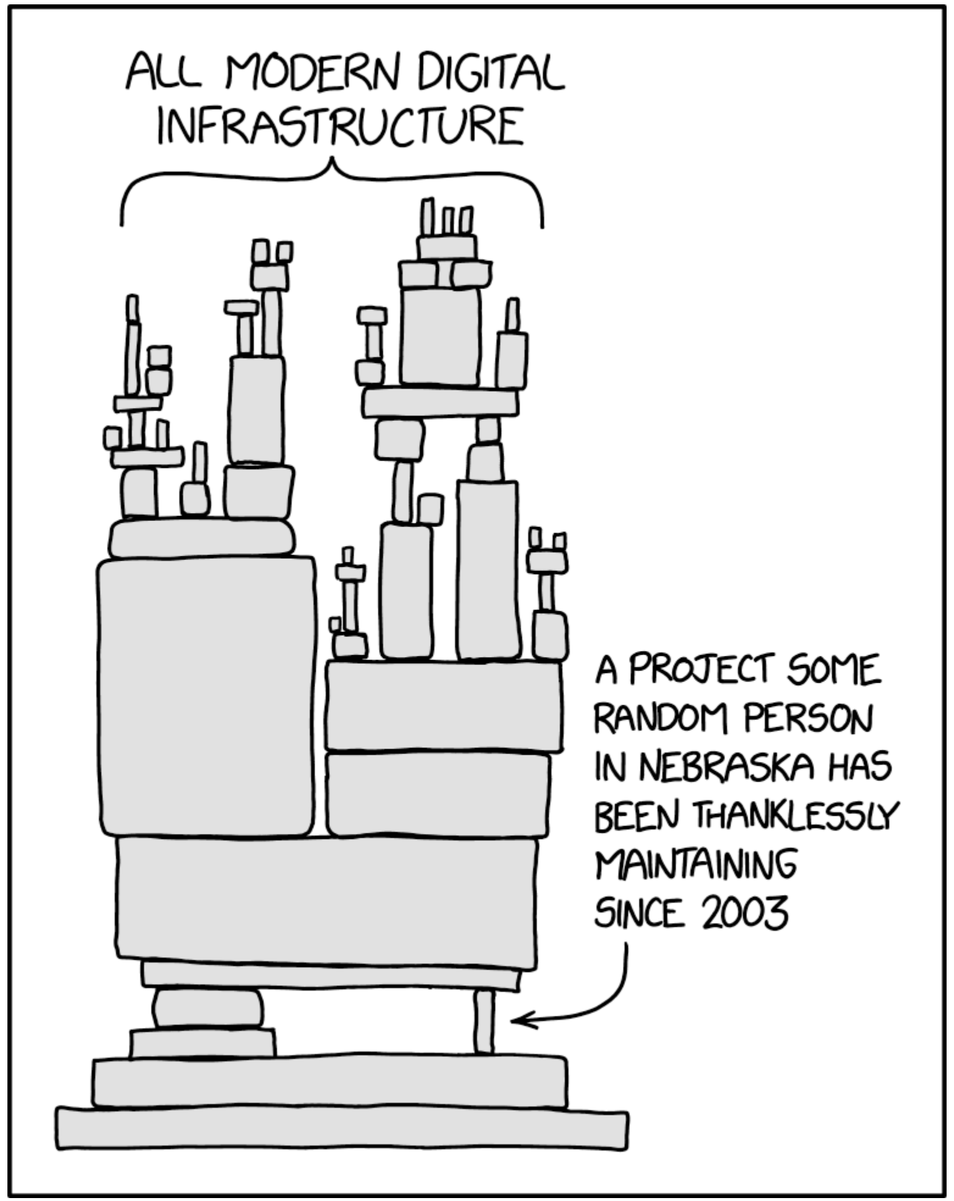
- and that’s probably an undercount


ALL MODERN DIGITAL INFRASTRUCTURE
A PROJECT SOME RANDOM PERSON IN NEBRASKA HAS BEEN THANKLESSLY MAINTAINING SINCE 2003

[xkcd #2347]

Why should we care?

Why should we care?

...because software is necessary for cumulative science

Publications are insufficent for reproducibility

"An article about computational science in a scientific publication is **not** the scholarship itself, it is merely **advertising** of the scholarship. The actual scholarship is the complete software development environment and the complete set of instructions which generated the figures."

— Buckheit and Donoho, 1995

Sharing code and data is hard!

And so knowledge is lost.

LabForComputationalVision / **plenoptic** Public

Notifications | Fork 1 | Star 20

Code | Issues 55 | Pull requests 5 | Actions | Projects 1 | Wiki | Security | Insights

main | **8** branches | **1** tag | Go to file | Code

billbrod Merge pull request #141 from LabForComputationalVision/jupyter_exec… ··· 262ec06 on Jan 13 **1,241** commits

.github	makes name of test step more informative	3 months ago
data	removes txt file from repo, download in notebook	11 months ago
docs	adds nblinks for newer tutorials	5 months ago
examples	Merge branch 'main' of github.com:LabForComputationalVision/plenopt…	3 months ago
jenkins	can now run pytest tests, instead of individually	5 months ago
plenoptic	add _signal_shape attribute to Synthesis	3 months ago
tests	Merge branch 'main' of github.com:LabForComputationalVision/plenopt…	3 months ago
.coveragerc	adds codecov	2 years ago
.gitignore	gitignore npy npz mat files	4 months ago
.readthedocs.yml	fixes docs issues!	2 years ago
CODE_OF_CONDUCT.md	adds code of conduct	2 years ago
CONTRIBUTING.md	Merge branch 'main' of github.com:LabForComputationalVision/plenopt…	3 months ago
LICENSE	Initial commit	3 years ago
README.md	add research notice to readme	10 months ago
setup.py	extract dependencies to requirements.txt	13 months ago

README.md

plenoptic

License MIT | python 3.6|3.7|3.8 | build failing | docs passing | stability alpha | DOI 10.5281/zenodo.3995057 | codecov 75%

tutorials passing | launch binder

About

Visualize/test models for visual representation by synthesizing images.

plenoptic.readthedocs.io/en/latest/

Readme

MIT License

Code of conduct

20 stars

7 watching

1 fork

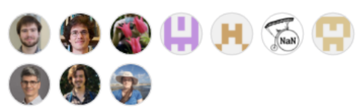
Releases

1 tags

Packages

No packages published

Contributors 10

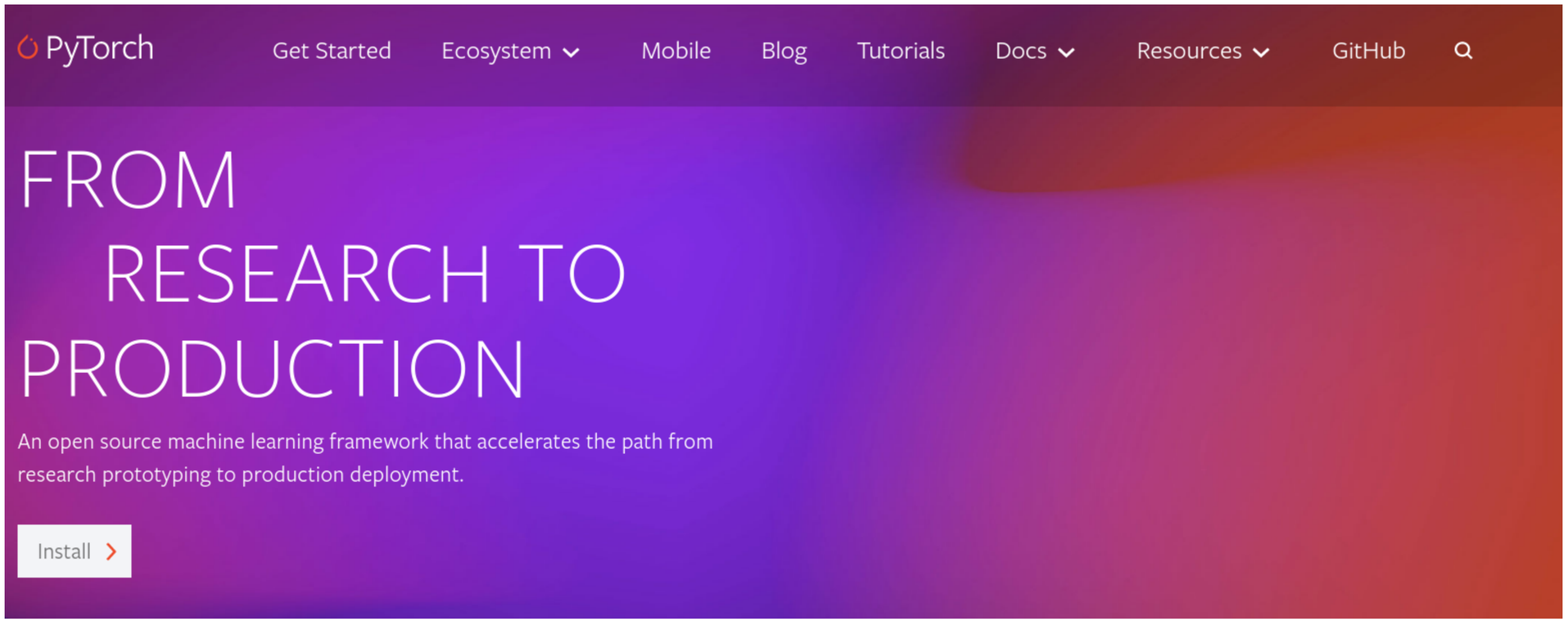


Languages

Python 99.9% **Dockerfile** 0.1%

plenoptic contents

- **Metamer**: my second chapter, Freeman and Simoncelli 2011, Portilla and Simoncelli 2000
- Eigendistortion: Berardino et al. 2017
- Geodesics: Hénaff and Simoncelli 2015, Hénaff et al. 2019
- MAD Competition: Wang and Simoncelli 2008
- Models: Portilla-Simoncelli texture statistics, **Steerable Pyramid**, FrontEnd models from Berardino et al. 2017


PyTorch
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Docs
Resources
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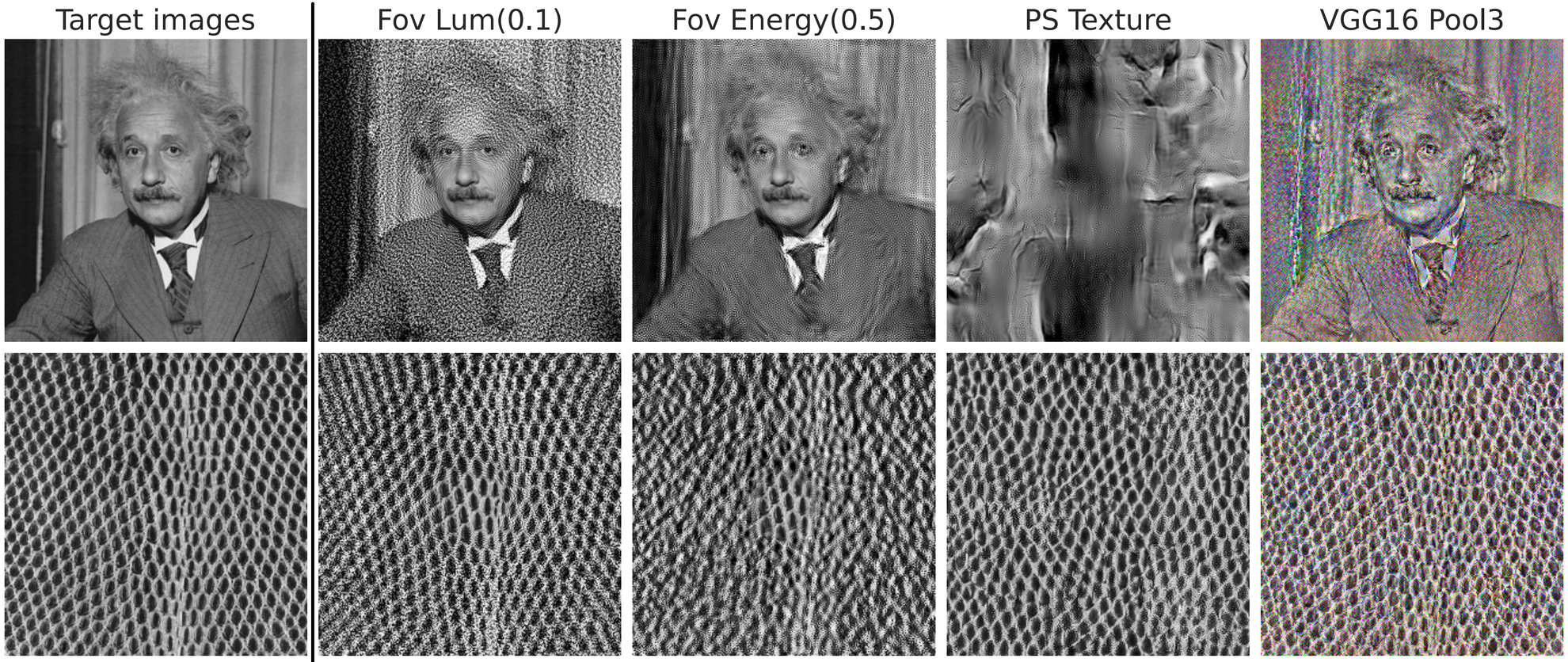
FROM
RESEARCH TO
PRODUCTION
An open source machine learning framework that accelerates the path from research prototyping to production deployment.
Install

General, model-agnostic implementations of synthesis methods


Target images
Fov Lum(0.1)
Fov Energy(0.5)
PS Texture
VGG16 Pool3

Summary

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- Discussed importance of open-source software
- Described **plenoptic**, python package for models and synthesis methods

Created by WFB.